Geology and Ground-Water Resources of Prowers County, Colorado

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GEOLOGY AND GROUND-WATER RESOURCES OF PROWERS COUNTY, COLORADO

By Paul T. Voegeli, Sr. and Lloyd A. Hershey

ABSTRACT

Ground water is one of the principal natural resources of Prowers County. This county, in the southeastern part of Colorado, has an area of 1,636 square miles, about half of which is devoted to ranching and the remainder to farming. All of the county is within the Great Plains physiographic province. The southeastern and northeastern parts lie within the relatively flat High Flains section of the province and the other part in the Colorado Piedmont section, which has greater local relief. Both sections are drained by intermittent streams which flow into the perennial Arkansas River. Sand dunes have encroached upon both sections. The climate is semiarid; the average annual precipitation is about 15 inches.

More than half the rocks exposed in the county are of Tertiary and Quaternary age. Rocks as old as Permian crop out in the vicinity of Two Buttes. The Ogallala Formation and younger deposits including the Meade(?) Group, alluvium, and dune sand underlie more than half the county. The remainder is underlain chiefly by rocks of Triassic, Jurrassic, and Cretaceous age. Rocks of Cretaceous age constitute nearly all of the Mesozoic rocks exposed in the county.

The four principal aquifers are the Ogallala Formation, the alluvium, the Dakota Sandstone, and the Cheyenne Sandstone Member of the Purgatoire For-The Ogallala Formation yields water to domestic and stock wells and also to irrigation wells in a few areas. The alluvium of the Arkansas River is the chief source of water for large-capacity irrigation wells and for many stock and a few domestic wells. The alluvium of the intermittent streams tributary to the Arkansas River is capable of yielding water to domestic and stock wells in many places. In some places, the chemical quality of the water in the alluvium precludes its use as a desirable domestic supply. The Dakota Sandstone furnishes water for many domestic, public-supply, and stock wells. The Cheyenne Sandstone Member of the Purgatoire Formation yields water to some domestic, public-supply, and stock wells. Most of the well~ penetrating the Cheyenne Sandstone Member also obtain water from the Dakota Sandstone. Large-capacity irrigation wells tapping three aquifers, the Ogallal Formation, the Dakota Sandstone, and the Cheyenne Member of the Purgatoire, have been developed south of Holly, Colo.

Ground water in the unconsolidated materials moves generally eastward over an irregular bedrock surface. The saturated zone ranges widely in thickness and is as much as 200 feet thick southwest of Holly. In the flood plain it is commonly within 5 feet of the land surface, whereas in adjacent upland areas the zone may be 100 feet deep.

Water in the Dakota and the Cheyenne Member of the Purgatoire generally moves northeastward along the dip.

The alluvium and terrace deposits contain large amounts of water and are capable of yielding large quantities to wells. The deposits in the Arkansas River valley are estimated to contain 1,000,000 acre-feet of water. Coefficients of transmissibility are high, ranging from 200,000 to 450,000 gpd (gallons per day) per foot.

The ground-water reservoirs of Prowers County are recharged by precipitation in the area, by seepage from intermittent streams, canals, and the Arkansas River, by spreading of irrigation water, and by underflow from adjacent areas. The reservoirs are discharged by movement into adjacent areas to the north and east, by evaporation and transpiration in areas of shallow water table, by seepage into streams and canals, and by wells.

Most of the 1,200 or more wells in the county are domestic and stock wells. The greatest number of the 160 large-capacity irrigation wells in the county are in the Arkansas River valley. Some of the artesian wells flow; however, most wells obtaining water from artesian sources are equipped with pumps.

The most favorable areas for the development of large-capacity wells are in the alluvium of the Arkansas River valley and the associated terraces, in the Ogallala Formation in the northeastern part of the county, and in the southeastern part of the county where wells tap a section comprising the Ogallala Formation, the Dakota Sandstone, and the Cheyenne Member of the Purgatoire Formation.

Ground water in Prowers County is suitable for irrigation, and some is suitable for most other uses. Most of the water is hard and in places contains constituents that may be objectionable for most uses. Water having the best chemical quality is obtained from the Ogallala Formation. In some of the alluvial water, high concentrations of sulfate preclude its use for domestic supplies. The chemical quality of water from the alluvium, Dakota, and Cheyenne Member of the Purgatoire ranges between wide limits, but the quality of water from the Ogallala is more uniform.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation of the geology and ground-water resources of Prowers County, Colo., was begun in August 1955 as part of the program of ground-water investigations in Colorado in cooperation between the Colorado Water Conservation Board and the U.S. Geological Survey. The purpose of the study was to determine the origin, movement, chemical quality, and availability of ground water for domestic, stock, irrigation, industrial, and public supplies. The investigation was under the direct supervision of Thad G. McLaughlin, former district geologist, U.S. Geological Survey, in charge of groundwater investigations in Colorado.

Ground water is one of the principal natural resources of Prowers County because nearly all the domestic and stock supplies are obtained from wells. Irrigation water from wells, to supplement surface-water supplies or to irrigate areas where surface water is not available, is a vital part of the economy of Prowers County. There is, therefore, a need for an adequate understanding of the ground-water resources to properly facilitate its safe and efficient development.

LOCATION AND EXTENT OF THE AREA

Prowers County is located along the Arkansas River between lat 37°38′ and 38°16′ N. and long 102°02′ and 102°45′ W. (See fig. 1.) The county has an area of 1,636 square miles.

PREVIOUS INVESTIGATIONS

The geology and ground-water resources of part of Prowers County were described briefly by Gilbert (1896b, p. 551-601) in his report on the Arkansas River valley in eastern Colorado. Johnson (1901, 1902) discussed the utilization of the High Plains, including a part of Prowers County. Parts of the county were described in Darton's report (1906) of the geology and ground-water resources of the Arkansas River valley in eastern Colorado, and all of Prowers County was discussed in his report on the geology and ground-water resources of the central Great Plains (1905, p. 352-354).

No comprehensive report of the geology or ground-water resources of Prowers County had been published at the time this investigation was begun (1955). Detailed studies have been made of the geology and ground-water resources of several adjoining areas, including Baca County, Colo., (McLaughlin, 1954); Hamilton Courty, Kans., (McLaughlin, 1943); and Stanton County, Kans., (Latta, 1941).

METHODS OF INVESTIGATION

The fieldwork upon which this report is based was done during the field seasons of 1955-58. The writers were assisted in the field by: Verle M. Burtis (well inventory), W. D. E. Cardwell (preliminary reconnaissance of project area and well inventory), Donald L. Coffin (well inventory), Harold A. McGovern (well inventory), Paul A. Schneider, Jr. (test drilling), and Allan C. Utter (well inventory).

Records of about 1,200 wells were obtained. The records of the wells and a map showing their locations are included in ε basic-data report (Voegeli and Hershey, 1960). The water levels in most of the wells were measured. Reported depths and water levels of other wells were provided by well owners, tenants, drillers, ε nd records from the Colorado Water Conservation Board. Data on the character and the thickness of water-bearing materials, the yield and drawdown of wells, and the general chemical quality of the water were obtained from the same sources.

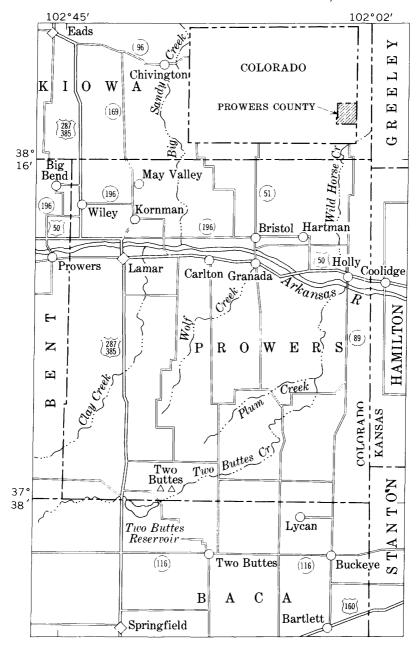


FIGURE 1.-Area described in this report.

The mineral content of water from 50 wells and 1 spring was determined by the Quality of Water Branch of the Geological Survey at Denver, Colo. The radiometric properties of water from six wells also were determined.

Information on the geology and ground-water resources of the county was supplemented by test drilling. The 145 test holes drilled by private contractors for the Geological Survey were in areas where few or no data were available. Cuttings from the test holes were examined by Lloyd A. Hershey, U.S. Geological Survey. More than 1,200 additional logs of wells, test holes, and seismograph shotholes were obtained from well owners, drillers, and oil companies.

Seven aquifer tests were made at the sites of large-capacity irrigation wells in the sand and gravel aquifers of the county. Flow tests were made of several artesian wells obtaining water from the Dakota Sandstone by Edward D. Jenkins, Woodrow W. Wilson, and the writers.

The geologic formations, except dune sand, were mapped in the field. The data on distribution of dune sand were taken from unpublished soil maps by the U.S. Soil Conservation Service and transferred to the geologic map by Donald L. Coffin. Altitudes of test holes were determined by Verle M. Burtis.

ACKNOWLEDGMENTS

The investigation was greatly benefited by the splendid cooperation and interest of many residents, public officials, and personnel of private companies. The writers are grateful to the ranchers and farmers, who provided basic well information and permitted measurements and tests of their wells. Special thanks are given Raymond McMillin, Harry Nevius, James Romer, George Russell, and Lail Schmidt, who provided much basic well information and were especially helpful in pointing out specific water problems. The writers appreciate the help of the municipal officials of Lamar, Wiley, Holly, and Granada, who suplied information on their community water supplies. For most of the logs obtained during the investigation, the writers are indebted to the following drillers and organizations: Henry Bechtold, Les Canfield, Tony Dreiling, Joe Gunn, Earl Hoffman, William Smith, Preston Wilson, and to the Atchison, Topeka and Santa Fe Railway Co., Amerada Petroleum Corp., California Co., Carter O'l Co., Gulf Oil Corp., Phillips Petroleum Co., Pure Oil Co., and Shell Oil Co. Thanks are extended to Orville A. Parsons, Area Soil Scientist, U.S. Soil Conservation Service, and to his staff for providing information on soils and irrigation-well distribution.

WELL AND TEST-HOLE NUMBERING SYSTEM

The well and test-hole numbers in this report are based on the U.S. Bureau of Land Management system of land subdivision. The number shows the location of the well or test hole by township, range, section, and position within the section. A graphic illustration of this method of location is shown in figure 2. The first numeral indicates the township, the second indicates the range, and the third indicates the section in which the well or test hole is situated. Lowercase letters following the section number locate the well or test hole within the section. The first letter denotes the quarter section, the second letter denotes the quarter-quarter section, and the third letter denotes the quarter-quarter-quarter section. The letters are assigned in a counterclockwise direction, beginning with "a" in the northeast quarter of the section. Letters are assigned to each quarter-quarter section and each quarter-quarter-quarter section in the same manner. If more than one well or test hole occurs in a quarter-quarter-quarter section, consecutive numbers beginning with 1 are added to the letters. For example, the number 21-45-24cda1 indicates a well in the northeast quarter of the southeast quarter of the southwest quarter of sec. 24, T. 21 S., R. 45 W., and shows that this well is the second inventoried in the quarter-quarter-quarter section.

In several parts of the county, sections are greater than 1 mile in the north-south direction. The "tall" sections are subdivided in the same manner as the normal sections. The additional length is com-

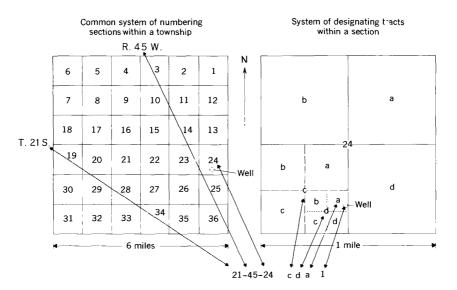


FIGURE 2.—System of numbering wells and test holes in Colorado.

pensated for by adjusting the size of the northern row of quarterquarter-quarter sections. Figure 3 shows the application of the well and test-hole numbering method applied to a "tall" section.

GEOGRAPHY

TYPOGRAPHY AND DRAINAGE

Prowers County lies entirely within the Great Plains physiographic province. The southeastern and northeastern parts of the county lie within the High Plains section, and the remainder lies within the Colorado Piedmont section. The area ranges in altitude from 4,716 feet at the highest point on Two Buttes in the southwestern part of the county, to about 3,340 feet where the Arkansas River leaves Colorado. The total relief is about 1,380 feet.

That part of the county in the High Plains section is underlain by Tertiary and Quaternary sediments. In much of the area, these flat-lying sediments are slightly dissected by intermittent streams. Dissection is more pronounced along Two Butte Creek in the south-

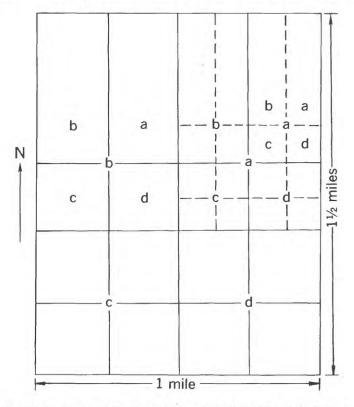


FIGURE 3 .-- System of numbering wells and test holes in a "tall" section.

eastern part of the county and Wild Horse Creek in the northeastern part. In the east-central part bordering the east bank of Two Butte Creek, the surface of the plain has been modified by encroachment of sand dunes (fig. 4).

Relief is greater in the Colorado Piedmont part of the county than it is in the High Plains parts. Only scattered remnants of Tertiary and Quaternary deposits remain in the Colorado Piedmont part (fig. 5). The underlying rock units have been eroded and in many places moderately steepsided valleys have been formed. Differential erosion between the shale, sandstone, and limestone has produced a variety of local landforms.

The most prominent topographic feature in the area is Two Buttes in the southwestern part of the county (fig. 6). This feature, a major landmark in southeastern Colorado, rises 400 feet above the surrounding plain, culminating in two small flat-topped buttes.

Prowers County is drained by the east-flowing Arkansas River and its numerous tributaries (fig. 1). Except for drainage in the extreme southeastern part of the county, all the tributary streams in the area



FIGURE 4.—Flat upland area in east-central Prowers County underlain by the Ogallala Formation that has been modified by the encroachment of dune sand. Contact dashed where approximately located. Aerial photograph by the U.S. Department of Agriculture.

enter the Arkansas River in Prowers County. The relatively minor drainage system in the southeastern part of the county flows into Stanton and Hamilton Counties, Kans.

CLIMATE

The mean annual precipitation in Prowers County ranges from 14 inches in the western part to 15 inches in the eastern part. Precipitation is greatest during the principal growing season from May through August and least from October through March. The mean annual precipitation, in inches, for the following localities in and near Prowers County is: Eads, 13.64; Holly, 15.08; Lamar, 14.02; and Two Buttes, 14.21.

June, July, and August are usually the warmest months and December and January the coldest. The daytime temperatures during the summer are high, but generally the nights are cool. The cool nights in southeastern Colorado are chiefly due to the altitude, low relative humidity, and moderate to strong winds. The winters are generally moderate.

MINERAL RESOURCES

Ground water is the most highly developed and most abundant mineral resource in Prowers County. In addition to ground water, some raw construction materials are available.

The first deep oil prospect in Prowers County was drilled 4 miles east of Lamar in 1908. During the past 50 years at least 40 deep oil prospects have been drilled in the county, and, since the early 1950's, the search for petroleum and natural gas has increased. One prospect in the south-central part of the county is reported to have yielded gas in commercial quantities.

Sand, gravel, rock for crushing, and structural stone are available in different parts of the area. Sand and gravel are available chiefly from the alluvium and terrace deposits of the Arkansas River. Locally, in the northeastern part of the county, the Ogallala Formation provides gravel of good quality; however, the best, although not extensive, sources are the terrace deposits on the north side of the Arkansas River. The white limestone of the Fort Hays Limestone Member of the Niobrara Formation lends itself to being crushed readily and has been used as road metal in several parts of the county. It weathers rather rapidly, however, and is not stable for long periods when subjected to heavy loads. The Dakota Sandstone has been used in the construction of bridges, homes, and outbuildings. Buildings, more than 70 years old, constructed of selected Dakota Sandstone show little effects of weathering. Except for iron staining, which may or may not be an objection, selected blocks of Dakota Sandstone make



FIGURE 5.—Well-developed drainage patterns cut into bedrock formations overlain by remnants of the Meade(?) Group and Ogallala Formation in southwestern Prowers County. Contact dashed where approximately located. Aerial photograph by the U.S. Department of Agriculture.



FIGURE 6.—Two Buttes viewed 3.5 miles east.

good structural stone. In some areas, the limestone of the Bridge Creek Limestone Member of the Greenhorn Limestone has been quarried and used as structural stone. Although many layers of bentonite occur in the Cretaceous deposits in the area, none are of commercial value.

Underground installations such as fallout shelters could be readily excavated with proper equipment in the thick shale members of the Cretaceous deposits. Where these deposits are exposed, engineering and construction problems resulting from ground-water influences generally would be negligible.

POPULATION

The distribution of population in Prowers County is influenced by the availability of water, modern agriculture practices, and transportation facilities. Both urban and rural populations tend to be concentrated where abundant water supplies are readily available. The improvements in farm machinery, the trend toward larger tracts of land managed by fewer people, and improvements in transportation allowing people to live in town and commute to their farms have all reduced the rural population.

According to the 1960 census, the population of Prowers County was 13,296; Lamar, the county seat and largest community, had a population of 7,369. Populations of other incorporated communities in 1960 were as follows: Holly, 1,108; Granada, 593; Wiley, 383; and Hartman, 164.

AGRICULTURE

For many years farming in Prowers County generally was restricted to areas in and near the Arkansas River valley. Because of recent developments of farm machinery, farming practices, and drought-resistant plants, much of the land formerly used for grazing is now under cultivation, as indicated by the following table:

Cropland and grazing land in Prowers County in 1940 and 1958

	Acr	eage
	1940	¹ 1958
Grazing land	717, 000	487,000
Cropland	252,000	470,000
¹ Data from James Read, county agent of Prowers County.		

Despite the increase in the number of acres in cropland, the greater share of the land is still used for grazing of cattle and sheep. More than 80 percent of the acreage of the principal cropland is used for growing wheat and sorghums. Between 1950 and 1958, the acreage of wheat increased from 100,000 to 163,000; however, the acreage of some other crops decreased. (See following table.)

Acreage of principal crops grown in Prowers County in 1950 and 1958

	Ac	res
Crops	¹ 1950	
Winter wheat	100,000	163,000
Sugar beets	6,000	3, 300
Alfalfa	27,000	38, 000
Corn	16,000	5,000
Sorghums	93, 000	120,000
Miscellaneous (oats, barley, hay)	35, 000	10,000

¹ Data for 1950 from Colorado Department of Agriculture and the U.S. Department of Agriculture (1951, p. 30-41).

GENERAL GEOLOGY

SUMMARY OF STRATIGRAPHY

Prowers County is underlain by deposits of limestone, shale, sandstone, sand, and gravel ranging in thickness from about 5,500 feet in the northwestern part of the county to about 7,000 feet in the southeastern part. More than 99 percent of the rocks that crop out in Prowers County are of sedimentary origin; the remainder are of igneous origin. The exposed sedimentary rocks range in age from Permian to Quaternary, and the igneous rocks, chiefly dikes, are of Tertiary age. The areas of outcrop of the formations are shown on the geologic map. (Pl. 1). The oldest rocks exposed crop out in an area south of Two Buttes along Two Butte Creek. These rocks are of Permian age and are, in ascending order, the sandstone of Whitehorse age, Day Creek Dolomite, and the Taloga Formation (of Cragin) (Cragin, 1897). The Triassic rocks are the Dockum Group, which crops out in areas southwest and southeast of Two Buttes. The Jurassic formations are the Entrada Sandstone, the middle unit of Jurassic age, and the Morrison. The Cretaceous formations are the Purgatoire, Dakota Sandstone, Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara. The Tertiary formations are the igneous rocks and the Ogallala. The Quaternary formations are the Pleistocene Meade (?) Group and the terrace deposits. The rocks also include undifferentiated Quaternary and Tertiary deposits and alluvium and dune sand of Recent age.

A generalized section of the geologic formations exposed in Prowers County is given in table 1. A brief summary of the geologic history of the area is given in the following pages; more detailed discussions of the geologic formations and their water-bearing properties are on pages 52 to 91.

STRUCTURE

Prowers County is on the east limb of the broad Las Animas arch. The effect of the arch upon the formations is revealed by the regional tilt of the exposed formations. The tilt is less than one-half a degree

² Data for 1958 from James Read, county agent of Prowers County.

per mile northeast. Three normal faults of post-Cretaceous age were discovered. The maximum displacement along any of the major faults is about 200 feet. Several minor faults were also found. The most extensive of the three major faults has a fault trace of about 16 miles. The fault extending from Lamar east-northeast across Big Sandy Creek has been traced in the subsurface for about 12 miles. The fault about 5 miles south of Holly is the extension of a major fault in Hamilton and Kearny Counties, Kans.

GEOLOGIC HISTORY

The following discussion of the geologic history of the area is based largely on reports by Mahler (1946), Maher and Collins (1949), Oriel and Mudge (1956), and McLaughlin (1954).

PALEOZOIC ERA

The Precambrian rocks underlying Prowers County were being eroded at the beginning of the Paleozoic Era, but before the end of the Cambrian Period, the area was invaded by a widespread sea. This sea deposited a thick sequence of limestone and dolomite during the remainder of the Cambrian and part of the Ordovician Periods. Rocks of Silurian and Devonian age have not been penetrated in oil-prospect holes in Prowers County, and they probably never were deposited here. After the Devonian Period, the county was again submerged, and more than 3,000 feet of marine deposits were laid down during Carboniferous and Early Permian time. These deposits were overlain by nonmarine sediments in Late Permian time.

MESOZOIC ERA

Erosion and the deposition of continental sediments characterized the early part of the Mesozoic Era. Sandstone and a lesser amount of variegated shale were deposited during the Triassic Period. During early Jurassic time, the area was eroded, and during the last part of the period, continental sediments comprising the Entrada Sandstone, the middle unit of Jurassic age, and the Morrison Formation were deposited over most of Prowers County.

In Early Cretaceous time the Purgatoire Formation, consisting of the continental Cheyenne Sandstone and the marine Kirwa Shale Members, was deposited. Near the end of Early Cretaceous time, the sea withdrew, and the sandstone and sandy shale constituting the Dakota Sandstone were deposited. At the start of Late Cretaceous time a widespread sea again covered the area; the shale and limestone of the Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation were deposited. The Pierre Shale and other Upper Cretaceous deposits do not occur in Prowers County; if they were deposited, they were removed by subsequent erosion.

Table 1.—Generalized section of the geologic formations

System	Series	Subdivision	Member	Thickness (feet)	Physical character	Water supply
	Recent	Dune sand		∓08-0	Very fine to coarse poorly sorted sand.	Yields water to a few stock wells. The dunes are of primary importance as catchment areas for recharge by precipitation.
Quaternary	Recent and Pleistocene(?)	Alluvium and terrace deposits		±00€-0	Sand, gravel, cobbles, and boulders: contain chiefly sand in small stream valleys.	Yield as much as 3,000 gpm in the Arkansas Valley. Yields adequate quantities of water to domestic and stock wells in small stream valleys.
		Undifferentiated		0-115	Sand and gravel.	Yield water to domestic and stock wells, and in some places adequate quantities for irrigation wells.
	Pleistocene	Meade(?) Group		-25±	Silt, sand, and gravel.	Lies above water table, hence yields no water to wells.
Tertiary	Pliocene	Ogallala Formation		0-440	Clay, silt, sand, gravel, caliche, and algal limestone. Finer sediments predominate in southern part of county.	Yields adequate quantities of water to domestic and stock wells in most parts. Yields as much as 1,500 gpm possible in extreme north- eastern part.
	Miocene(?)	Intrusive rocks		0-100±	Porphyry dikes.	Yield no water to wells.
		Michael Domestice	Smoky Hill Marl	150 ±	Chiefiy yellowish chalk; contains thin beds of white limestone.	Do.
		TVIODIAIA FOITHAVIOH	Fort Hays Limestone	20-60	Chalky limestone and marl.	Yields water to stock wells and from springs north of the Arkansas River.
			Codell Sandstone	∓27	Chiefiy sandy shale; contains calcareous sandstone.	Yields water to a few stock wells.
		Carlile Shale	Blue Hill Shale	2060	Chiefiy black noncalcareous fissile shale, contains concretions in upper part.	Yields limited quantities of water from seeps north of the Arkansas River.
	Trans		Fairport Chalky,	100-125	Chalky shale; contains thin chalky limestone beds in lower part.	Yields water to a few stock wells.
	Cretaceous		Bridge Creek Limestone	69–73	Thin-bedded limestone and shale.	Ďo.

		Č	Hartland Shale	20-38	Chalky shale and thin-bedded lime- stone; contains thin layers of ben- tonite.	Yields no water to wells.
Cretaceous		Creeniorn	Lincoln Limestone	25-37	Thin-bedded hard crystalline lime- stone and calcareous shale; contains thin layers of bentonite.	Do.
		Graneros Shale		85-100	Gray to black gypsiferous shale and thin layers of bentonite; contains thin-bedded rusty limestone in mid- dle to lower part.	До,
		Dakota Sandstone		150-235	Fine-grained thin-bedded to massive sandstone; contains clayey to sandy shale. Color ranges from white to brown.	Yields adequate water for domestic and stock use in most places. In some areas it yields enough water for municipal and industrial supplies.
	Lower	Purgatoire	Kiowa Shale	30-140	Gray to black calcareous clayey shale; thin-bedded fine-grained sandstone in upper part.	Yields no water to wells.
	Cretaceous	Formation	Cheyenne Sand- stone	30-200	Massive white to buff fine-grained sandstone.	Yields small to large quantities of water for domestic, stock, industrial, municipal, and irrigation use.
		Morrison Formation		20-240	Varicolored marl: locally contains thick sandstone lenses, thin beds of conglomerate, and platy limestone.	Yields water to some domestic and stock wells north of Two Buttes.
Jurassic	Upper Jurassic	Middle unit of Jurassic age		35-150	Sandstone, limestone, mudstone conglomerate, and chert zones.	Yields no water to wells.
		Entrada Sandstone		100±	Massive white to buff crossbedded fine- to medium-grained sandstone.	Do.
Triassic	Upper Triassic	Dockum Group		150-540	Chiefly sandstone, but locally contains thin beds of conglomerate, limestone, and shale.	Dο.
		Taloga Formation (of Cragin)		100-400	Red siltstone and fine-grained sandstone.	Do.
Paimien	Typper Permian	Day Creek Dolomite		10-60	Dolomite, anhydrite, or gypsum.	Do.
		Sandstone of Whitehorse age		30-300	Buff to red fine-grained sandstone and red shale.	Do.

CENOZOIC ERA

During the Cenozoic Era, the older rocks were eroded, were covered by continental deposits derived chiefly from the erosion of the rising Rocky Mountains to the west, intruded by igneous rocks, and were deformed by folding and faulting. Erosion continued until the middle of the Pliocene Epoch when the silt, sand, gravel, and caliche of the Ogallala Formation were deposited over the area.

One of the most significant structural features in the area developed during this era when the intrusion of igneous rocks formed Two Buttes. The dome was formed after the deposition of the Cretaceous rocks and mainly before the Pliocene when the Ogallala Formation was laid down.

The Quaternary Period has been one of erosion and deposition. During the early part of this period, the Arkansas River began cutting its valley and depositing and reworking its sediments. Sometime during post-Ogallala time, igneous activity resumed locally. The Recent Epoch is marked by further cutting of deep channels in the Arkansas River valley, building of a flood plain, and deposition of dune sand along the south side of the Arkansas River valley. Other streams in the area are the same age as the Arkansas.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The following discussion on the occurrence of ground water is adapted in part from Meinzer (1923) and McLaughlin (1954, p. 21–23). The reader is referred to Meinzer's report for a more detailed discussion of the subject.

The rocks that form the outer crust of the earth generally contain many voids or interstices. These open spaces are the receptacles that hold the water below the surface of the land. Part of this water generally may be recovered through wells and springs. The amount of water that can be stored in any rock depends upon the volume of the rock that is occupied by open spaces. The capacity of a rock to yield water depends on the size, number, and interconnection of openings. Rocks that will not transmit water are said to be impermeable. Some deposits, such as dense silt or clay, may have a large proportion of open space, but, because of the small size of the pores, they transmit water slowly. Other deposits, such as well-sorted gravel containing large openings that are freely interconnected, transmit water readily. Part of the water in any deposit is not available to wells because it is held against the force of gravity by molecular forces fixing the water to the walls of the pores.

Below a certain zone the permeable rocks are saturated with water. The upper surface of this zone is called the "water table." Wells dug or drilled into the saturated zone will become filled with ground water to the level of the water table.

The rocks that lie above the water table generally contain some water. The water content may range from zero to near-saturation depending upon the material and the availability of moisture. The moisture content is changing continually as water is added or subtracted from the zone.

The sedimentary rocks penetrated by wells in Prowers County include several types that differ greatly in physical character and in their ability to store and transmit ground water. The chief types of sedimentary rocks are sand, gravel, sandstone, shale, and limestone.

SAND AND GRAVEL

Thick deposits of stream-laid sand and gravel constitute the alluvium of Recent age, the terrace deposits of Pleistocene (?) age, and the Ogallala Formation of Pliocene age in many places in Prowers County. In places where these deposits are well sorted and have a moderately uniform texture, wells yield adequate water to many domestic, stock, and irrigation wells. The largest yields can be obtained where the deposits are thickest.

In many parts of the county where the sand and gravel is thin or is poorly sorted and includes much silt and clay which fill the pore spaces, yields from wells are small. The abundance of fine material accounts for the small yields from the Ogallala Formation in the southeastern part of the county. The yields, however, are adequate for domestic and stock use.

SANDSTONE

Although most of the beds of sandstone in Prowers County are fine grained and firmly cemented and yield only small quantities of water to wells, some beds are capable of yielding large quantities. Where the sandstone is jointed or otherwise broken, water moves through the material more readily, and well yields are greater than where the beds are undisturbed. Larger quantities of water generally are available from wells tapping sandstone such as the Cheyenne Sandstone Member of the Purgatoire Formation, which is uniformly thick and poorly cemented. The principal sandstone aquifers in Prowers County are the Cheyenne and the Dakota.

SHALE

The shale in Prowers County yields little or no water to wells. Even where the shale is jointed or otherwise broken or contains sand,

it is incapable of yielding enough water for domestic or stock use. The shale in the Dakota Sandstone contains some water; however, it is the sandstone of the Dakota that yields the greater quantity.

Although the shale yields little or no water, it is important because it confines the water of the artesian aquifers. The Graneros Shale, overlying the Dakota Sandstone, and the Kiowa Shale Member, overlying the Cheyenne Sandstone Member of the Purgatoire Formation, confine the water under artesian pressure in the underlying materials in many places. Wells drilled into the Dakota Sandstone between Carlton and Lamar and into the Cheyenne Sandstone Member at Granada have sufficient artesian pressure to flow.

LIMESTONE

The limestone beds of the Cretaceous deposits in Prowers County are dense, compact rocks having few open spaces and, hence, poor water-yielding properties. Locally, the thin beds of limestone contain open joints that allow the passage of small quantities of water. In some areas, wells yield water for stock use from the Fort Hays Limestone Member of the Niobrara.

HYDRAULIC PROPERTIES OF WATER-BEARING MATERIALS

Pumping tests were made to provide information on the hydraulic properties of the Dakota Sandstone, the Ogallala Formation, the alluvium of Clay Creek, and the alluvium and terrace deposits of the Arkansas River. The test data were analyzed by the equilibrium method of Thiem (1906), the nonequilibrium method of Theis (1935, p. 520), the modified nonequilibrium method of Jacob (1944 and 1946), and Jacob and Lohman (1952). The results of the tests are summarized in table 2.

The capacity of a water-bearing material for transmitting water under a hydraulic gradient is known as its "permeability." The "coefficient of permeability" was expressed by Meinzer (Stearns, 1927, p. 148) as the rate of flow, in gallons per day, through a square foot of its cross section, under a hydraulic gradient of 100 percent at a temperature of 60° F. The "field coefficient of permeability" is the same, except that temperature is disregarded.

The "coefficient of transmissibility" was defined by Theis (1935, p. 520) as the number of gallons of water per day (gpd) transmitted through each 1-foot strip extending the height of the aquifer, at the existing temperature, and under a hydraulic gradient of 100 percent. This coefficient is Meinzer's coefficient of permeability adjusted for temperature and multiplied by the thickness of the aquifer, in feet.

Table 2.—Summary of the results of aquifer tests

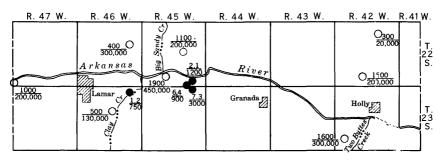
[Principal aquifer: Kd, Dakota Sandstone; To, Ogallala Formation; Qt, terrace deposits, Arkansas River; Qal, alluvium, Arkansas River; Qal, C, alluvium, Clay Creek]	Remarks	Flowing well. Do. Flowing well. Do. Basic data obtained by city of Lamar personnel.
alluvium,	Date of test	11-11-67 11-12-67 10-23-57 10-12-57 10-12-57 10-12-57 10-15-57 10-15-57 10-17-57 10-17-57 10-17-57
Qal, C,	Water tem- pera- ture (° F)	861 861 861 861 861 861 861 861 861 861
River;	Radius confi. Water of in. of in. of stor. perafluence age or ture (feet) specific (° F)	2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
rkansas	Radius of in- iuence (feet)	860 2,500 1,240 2,000
ıvium, A	Average field co- efficient of per- perme- ability of sand and gravel (gpd per sq ft)	3,000 10,000 3,000 5,000
Qal, allu	Average field co- efficient of per- perme- ability of entire aquifer (gpd per sq ft)	3,000 10,000 10,000 10,000 17,000 5,000 10,000
as River;	Coeffi- cient of trans- missi- bility (gpd per ft)	20,000 200,000 200,000 200,000 450,000 300,000 300,000 3,000 130,000
, Arkans	Specific capac- ity (gpm per ft for aw- down)	6 68 68 68 121 6 61 77 4 4 143 2
deposits	Draw- down (feet)	23 23 18 16 10 2.6 2.7 2.7 19.5 19.5 3.5
t, terrace	Average Draw- pump- down ingrate (feet) (gpm)	1, 600 1, 100 1, 100 1, 100 1, 600 1, 600 1, 600 1, 200 1,
ation; Q	Dura- tion of pump- ing (hours)	∞4∞5uu∞8uu-a
ıla Forn	Saturated sand and gravel (feet)	71 46 98 98 57 57
o, Ogalla	Total saturated thick-ness (feet)	75 77 77 46 46 67 29 57
stone; T	Depth to water below uring point (feet)	70 60.8 60.8 60.1 17.1 17.1 17.1 49.8 8.9 49.8 49.8 49.8 49.8 49.8 49.8
ta Sand	D Depth Depth boil (feet) (feet) (feet) (feet)	138 63 146 35 109
d, Dako	Depth of well (feet)	144 140 115 115 63 220 146 186 111 111 176 138 49
quifer: K	Princi. Depripal aqui- of w	Opt. Opt. Opt. Opt. Opt. Opt. Opt. Opt.
[Principal ac	Well	22-42-11bbb- 22-45-15dda

The "coefficient of storage" of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions, this quantity is approximately equal to the "specific yield." The specific yield of a rock or soil, with respect to water, has been defined by Meinzer (1923, p. 28) as the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume. Under artesian conditions, where aquifers are not dewatered by the withdrawal of water through wells, the coefficient of storage represents the water released from storage largely by the compaction of the aquifer. The coefficient of storage is expressed as a decimal fraction.

AQUIFER TESTS

The coefficients of transmissibility and storage of the alluvial deposits in and near the Arkansas River valley and in the Dakota Sandstone south of the Arkansas River between Carlton and Lamar, were determined at 12 places by aquifer tests (fig. 7).

The coefficients of transmissibility in the alluvium and terrace deposits of the Arkansas River ranged from 200,000 to 450,000 gpd per ft. This wide range may be attributed to the differences in saturated thickness of the deposits and to the differences in size, shape, and interconnections of the interstices. The coefficients of permeability based on the entire thickness of the saturated alluvial deposits ranged



EXPLANATION

Artesian well in Dakota Sandstone

Large-capacity irrigation or publicsupply well in unconsolidated deposits

Water pumped or flowing, in gallons per minute

Coefficient of transmissibility, in gallons per day per foot

FIGURE 7.—Map of part of the report area showing the location of aquif?r tests, the coefficients of transmissibility, and the pumping rates.

from 3,000 to 10,000 gpd per sq ft. The coefficients of transmissibility and permeability of the single test of the Ogallala was 20,000 gpd per ft and 300 gpd per sq ft, respectively.

In the Dakota Sandstone, the coefficient of transmissibility ranged from 800 to 3,000 gpd per ft. Such a wide range was expected because the sandstone differs widely in size and shape of particles and degree of cementation.

The calculated specific yield of wells in alluvium and associated deposits of the Arkansas River ranged from 10 to 20 percert. Values calculated for wells that were pumped for less than one day may be erroneous. A longer period of pumping is required if reliable figures of specific yield are to be obtained. The formula for calculating specific yield assumes that the deposits drain instantaneously as the head declines. In fine-grained materials, many days or weeks of pumping may be required for materials to become largely drained; in very coarse grained materials, the sediments may be largely drained within a few hours. Thus, the apparent specific yield of an aquifer under water-table conditions increases as pumping continues, rapidly at first and then more and more slowly until the true specific yield is approached or reached. In wells such as 22-47-31cbc1, additional pumping time was required to show specific yield. As shown in figure 8, the specific yield of the materials increased from 6 percent after 8

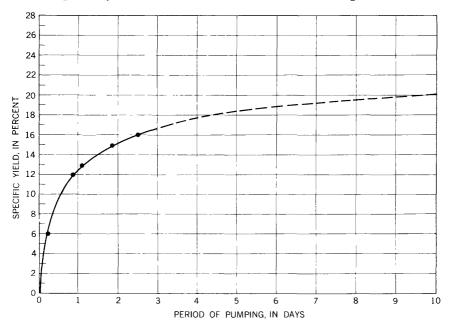


FIGURE 8.—Curve showing the increase in specific yield with duration of pumping of well 22-47-31cbc1.

hours of pumping to 16 percent after 2½ days of pumping. Projection of the curve indicates that specific yield after 10 days of pumping may exceed 20 percent.

None of the aquifer tests in the alluvium were disturted by the pumping of nearby irrigation wells nor by reentry of water from the tested wells into the aquifer in the vicinity of the pumped well.

The coefficient of storage calculated from wells 22–45–35ccd1 and -dba, which tap the Dakota, was 0.001; artesian conditions were thus indicated. No specific yield was determined for the Ogallala.

ARTESIAN CONDITIONS

Ground water that rises in wells above the level at which it is confined is said to be artesian. If the water rises high enough to flow at the surface, the well is termed a "flowing" artesian well. In many of the formations in Prowers County, strata of relatively permeable rock, principally sandstone, alternate with relatively impermeable rock, principally shale. The strata generally dip east-north astward. Water entering the more permeable beds in their areas of outcrop in the southwestern part of the county moves east-northeastward downdip between the confining layers of relatively impermeable strata and is therefore under artesian pressure.

The principal artesian aguifers in Prowers County are the Cheyenne Sandstone Member of the Purgatoire Formation and the Dakota Sandstone. The Chevenne Member is underlain by the relatively impermeable Morrison Formation and is overlain by the Kiowa Shale Member of the Purgatoire Formation. Water in the Chevenne Sandstone Member is under artesian pressure in all of Prowers County, except in and near areas where the Cheyenne Member crop? out. an area about 10 miles south of Carlton and at Granada, water in the Chevenne Member is under sufficient pressure to flow at the surface. Water is confined under pressure in the Dakota Sandstone where the formation is underlain by the Kiowa Shale Member of the Purgatoire Formation and overlain by the Graneros Shale. In the western part of the county south of the Arkansas River where the Dakota Sandstone is exposed, water may be locally under artesian pressure because it is confined by the relatively impermeable sandy shale beds within the unit; where these beds are absent, the water is unconfined. The principal area in the county where the water is under sufficient pressure to flow at the surface is a narrow belt south of the Arkansas River between Carlton and Lamar.

Artesian pressure has been noted in some of the wells in the alluvium of the Arkansas River. This pressure is not widespread and probably is associated with the clay lenses in the sand and gravel.

PIEZOMETRIC SURFACE

The imaginary surface to which water in a confined aquifer will rise in wells is called the "piezometric surface." The piezometric surface in the Dakota Sandstone was mapped by using as control points the altitude of water levels in most of the wells tapping the Dakota. Insufficient data were available to make a similar map for the Cheyenne Member of the Purgatoire. The piezometric surface of the Cheyenne Member probably is at a higher altitude than that of the Dakota, although the data upon which this conclusion is based are few. The configuration of the piezometric surface of the Dakota Sandstone is shown by contours on figure 9.

The piezometric surface slopes generally northeastward in keeping with the regional dip of the formation. A change from the regional slope is shown locally by the flexures of contours in the southwest corner of the county. The irregularity of the pattern in this area results from the structural disturbance caused by Two Buttes dome.

Ground water moves generally at right angles to the contours in the direction of the downward slope. The direction of movement of ground water is indicated by the slope of the piezometric surface.

The nonuniform shape and slope of the piezometric surface is caused by several factors. A steepening in slope may be caused by a decrease in permeability or thickness of the aquifer, by the discharge of ground water from springs and wells, or by restrictions of flow caused by faulting and folding.

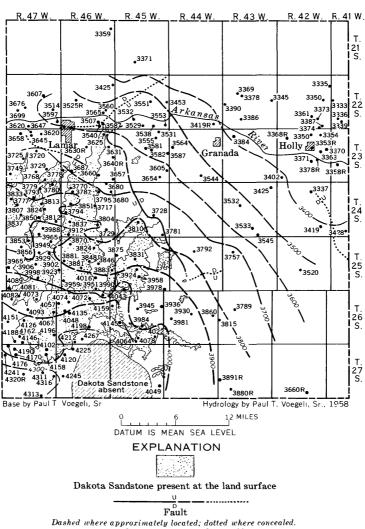
WATER-TABLE CONDITIONS

The lenticular arrangement of the sand, gravel, and clay layers are such that local artesian conditions exist within the alluvium; however, most of the water is under water-table conditions.

The water table, in general, is not a level or uniformly sloping surface but is irregularly shaped, although not nearly as much as the land surface. The configuration of the water table in Prowers County is shown on plate 2. The depth to the water table below land surface is shown on plate 3.

Irregularities in the slope and in the direction of the slope of the water table are affected by the same factors that affect the slope of the piezometric surface. Water moves at right angles to the contours and toward contours of lower altitude as it does in artesian aquifers.

In the Arkansas Valley and adjoining upland areas to the north the water table in the valley fill, the upland deposits, and the Carlile Shale and Niobrara Formation is continuous throughout most of the area. However, in the areas where the Ogallala Formation and undifferentiated Tertiary and Quaternary deposits are thin and overlie the bed-



U, upthrown side; D, downthrown side

-3500 -Contour on surface of water in the Dakota Sandstone Altitude, in feet, above mean sea level. Contour interval 100 feet

Well obtaining water from the Dakota Sandstone Number refers to altitude of water in well. Where reported data were used, numbers followed by "R"

FIGURE 9.—Altitude of the piezometric surface of water in the Dakota Sindstone, 1957-58.

rock, the water table is absent; such areas are indicated on the depth-to-water map by the notation "water table discontinuous." The water table in the southeastern part of the county is not continuous with that in the northern part. Geologic section H-H' (pl. 4) shows that the upland deposits north of the stream are dry. However, many parts of the terrace deposits north of the Arkansas Valley have perched water bodies.

The slope of the water table generally is much flatter than that of the piezometric surface in the artesian aquifers. The gradient of the water table in the valley generally ranges from 5 to 20 feet per mile, as compared to a slope of 100 feet per mile common in the Dakota Sandstone. The slope of the water table in the less permeable formations in the upland areas ranges from 20 to 120 feet per mile. However, in some areas, such as the northwestern part of the county where the Fort Lyon canal is recharging the water table, gradients exceed 120 feet per mile in places.

The slope of the water table in the bedrock formation is affected by the number and extent of fractures. Where the bedrock is extensively fractured, the water-table gradient flattens; where fracturing is less, the gradient steepens.

QUANTITY OF GROUND WATER IN STORAGE

Most of the ground water readily available for use in Prowers County, particularly for large-capacity wells, is in the alluvium of the Arkansas River and its terraces.

The quantity of ground water in storage in the sediments, based on field data obtained in 1957–58, is about 1,000,000 acre-feet. This amount is about twice the maximum storage capacity of the reservoir behind John Martin Dam in Bent County, Colo. Storage was determined by multiplying the volume of saturated material by a specific yield of 20 percent. The volume of the saturated materials was determined from the saturated-thickness map (pl. 5), which was based on the altitude of the water-table map (pl. 2), and the map (pl. 6) showing the altitude of the bedrock surface.

It is not practical to recover all the stored water. As the storage decreases, the water table declines and the pumping capacity of wells is reduced. At some level, perhaps 20 to 30 feet above the bottom of the alluvial deposits, the yield from large-capacity irrigation wells may be reduced so much that they will become uneconomical to pump.

At the present rate of irrigation-well development in the alluvium of the Arkansas River and its associated terraces, overdevelopment is not likely. Ground water that is presently being pumped from these sediments is being replaced by surface-water recharge at a rate at least equal to the withdrawal. During drought, when surface water is in short supply, the ground-water reservoir is capable of supplying sufficient quantities of water to irrigate the Arkansas Valley in Prowers County.

FLUCTUATIONS OF THE WATER TABLE

The water table is not stationary but varies in a manner somewhat similar to an open reservoir that fills and empties. The change in the amount of water in storage is reflected by the amount of change in the water level of the aquifer. Unlike a surface reservoir where changes in storage are readily discernible by observation of the water surface at any point on the reservoir, the water surface in the alluvium of the Arkansas River does not fluctuate uniformly. In some places, the water level will remain almost unchanged from day to day, whereas in other places it changes pronouncedly within a short time. Examples of both relatively stable and widely fluctuating water levels in the alluvium of the Arkansas River are shown in figure 10.

When recharge to an aquifer exceeds discharge, the amount of water in storage increases and the water table rises; when discharge exceeds recharge, the water table declines. The principal modes of recharge are from (1) irrigation, (2) the Arkansas River and its intermittent tributaries, (3) unlined canals and irrigation ditches, (4) precipitation, and (5) adjacent aquifers draining into the alluvial materials of the valley of the Arkansas. The principal modes of discharge are (1) withdrawals by pumping wells, (2) evapotranspiration, (3) seepage to springs and streams, and (4) subsurface outflow.

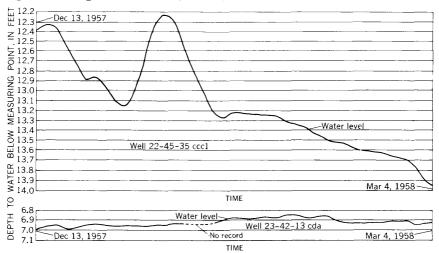


FIGURE 10.—Hydrographs showing fluctuations of water levels in two observation wells in the alluvium of the Arkansas River. Hydrographs are based on charts from recording gages.

Hydrographs of water levels in wells in the alluvium of the Arkansas River and associated deposits have been included for the purpose of comparing water levels in one part of the valley to another (figs. 11, 12).

The hydrographs show that water levels in the alluvium of the Arkansas River valley in Prowers County generally decline from late October through April, begin to rise in May, and reach their highest level from July to early October. The period of highest water levels coincides with the period of greatest recharge from irrigation applications, greatest losses from the stream and irrigation-distribution systems and greatest precipitation. The recharge is so great during this period that it obscures any local effects on water levels resulting from pumping, which is also at its maximum during this period. The decline in water level is the result of natural drainage and commences at the end of the irrigation season.

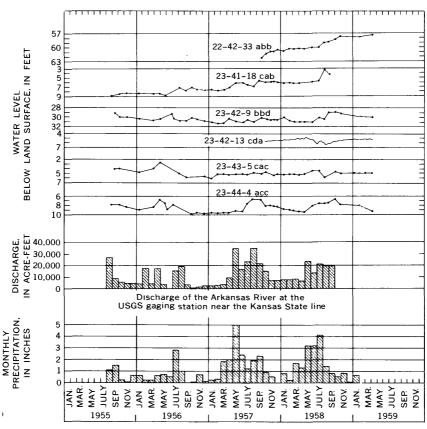


Figure 11.—Hydrographs of six wells within 12 miles of Holly, the Arkansas River near the Kansas State line, and the monthly precipitation at the Holly weather station.

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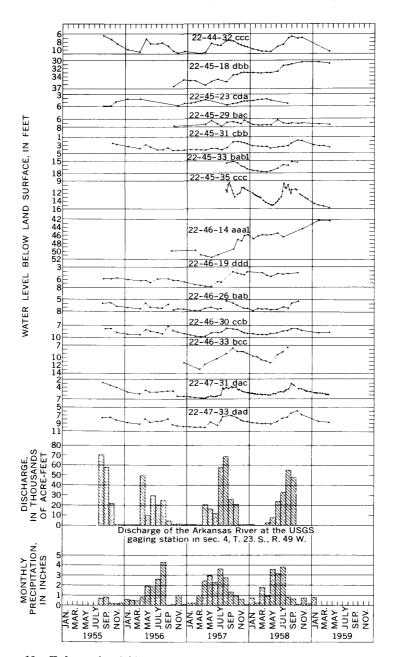


FIGURE 12.—Hydrographs of 14 wells within 12 miles of Lamar, the Arkansas River in T. 23 S., R. 49 W., and the monthly precipitation at the Lamar weather station.

The average water level changes slightly from year to year, depending upon the availability of surface water for irrigation and the amount of precipitation. For example, the hydrographs show that during the years 1957–58, when an abundant supply of surface water was available for irrigation, water levels were generally higher than they were in 1956, when the surface supply was somewhat less.

In general, the water level in the Ogallala Formation fluctuates less, and less abruptly, than that in the alluvial materials. Figure 13 shows that the range of fluctuation is less than 2 feet during the period of record. The water levels fluctuate less chiefly because (1) the aquifer does not receive abundant recharge by streams and canals, (2) withdrawal from wells is relatively small, and, (3) discharge by evapotranspiration is negligible.

RECHARGE OF GROUND WATER

UNDERFLOW

The Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation are recharged by underflow resulting from surface drainage and precipitation to the west and southwest. In the vicinity of Two Buttes dome, where these formations have been completely or deeply eroded, the underflow pattern has ben disrupted.

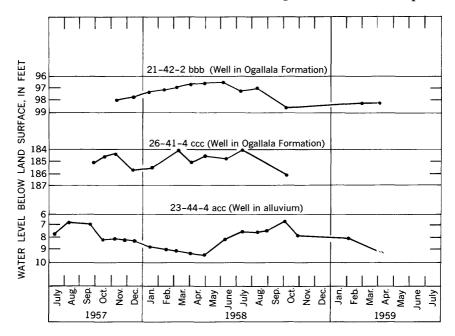


FIGURE 13.—Hydrographs of two wells in the Ogallala Formation and one well in the alluvium.

Water-table contours of the shallow ground water in the alluvial deposits of the Arkansas River clearly indicate that this ground water moves eastward. The quantity of water brought into the county by underflow is considerable.

STREAMS, CANALS, AND IRRIGATION WATER

A major source of recharge to the aquifers of Prowers County is from streams. Much water is lost to ground-water reservoirs by intermittent streams during periods of flow. The intermittent streams lie above the water table and, during periods of flow, water percolates downward through sandy bottoms into materials that conduct the water to the aquifers. Perennial streams may pick up water from the aquifer if the aquifer is draining at that point, or they may lose water if the water table slopes away from the stream. In general, recharge to the aquifer is more prevalent than discharge in Prowers County. In and near the channel of the Arkansas River, the shallow groundwater table is recharged in most of the county. The quantity of water reaching the water table in one place differs from that in another because of differences in permeability of the alluvium and differences in the slope of the water table. In places where the channel of the Arkansas River is in close hydraulic contact with bedrock formations, the river may gain water. Where ephemeral streams cut into sandstone aguifers, the streams lose water to the aguifer; the aguifers may also be recharged directly from precipitation. The measurement of water levels in wells, and logs of wells and test holes drilled in the river valley in Prowers County show that the Arkansas River is, in some places, a losing stream.

In the parts of Prowers County where unlined irrigation canals flow across permeable materials above the water table, the underlying aquifer is readily recharged. These permeable materials may be either sand and gravel, fractured or otherwise open-jointed material, or a combination of both. Some of the bedrock formations in Prowers County, such as the Fort Hays Limestone Member of the Niobrara, are jointed and fractured in places where they form the beds of canals. The amount of water lost at any one point may range from a few to several hundred gallons a minute. In some areas, the Fort Hays Limestone Member discharges as much as 120 gpm (gallons per minute) from fractures in the rock. Equal or greater quantities of surface water may discharge into aquifers where the bottoms of unlined canals are situated on fractured zones.

Another major source of recharge to the alluvial deposits of the Arkansas River is irrigation water spread on fields, which percolates downward into the zone of saturation. The quantity of water enter-

ing the aquifer in this way depends upon the texture of the soil, the permeability of the underlying alluvium, and the amount of water consumed by the plants. Recharge by irrigation flooding is greatly enhanced in some parts of the county where the soil zone is thin and permeable and alluvial materials closely underlie the land surface.

PRECIPITATION

Precipitation in the area evaporates, transpires, runs off, or recharges ground-water reservoirs. The average annual precipitation in Prowers County is about 14 inches. Only a small part of it ever reaches the ground-water reservoirs because the greatest amount of precipitation is in the summer, when evaporation and transpiration are highest.

Recharge from precipitation varies considerably throughout the county. The areas covered with dune sand offer the greatest opportunity for recharge. Water percolates downward rapidly through the permeable materials and dissolves very little mineral matter in transit. The result is that the underlying body of water is of good quality. The areas where the surface is composed of alluvial deposits, the Ogallala Formation, and the sandstone formations also are readily recharged but at a somewhat lesser rate than the sand dunes. Precipitation on areas underlain by shale or other rock types of low permeability either runs off or is retained in low areas and evaporated. The runoff from areas underlain by relatively impermeable materials is great compared to that from areas underlain by loose permeable material. Little or no water runs off the areas underlain by sanddune deposits, whereas on the shale surfaces, runoff has cut deeply and has eroded distinct drainageways.

UNDRAINED DEPRESSIONS

Precipitation stored in undrained depressions may enter the underlying rocks at a slow or at a more rapid rate, depending upon the permeability of the materials making up the depression. Most of the depressions consist of material of low permeability, and the greater part of water that drains into them is evaporated. In some places, such as depressions on the surface of the Fort Hays Limestone Member of the Niobrara Formation, water collects in low areas and percolates into the underlying rocks.

DISCHARGE OF GROUND WATER

In Prowers County, ground water is discharged by evaporation and transpiration, seeps, springs, wells, infiltration galleries, and by subsurface outflow. The principal methods of discharge are discussed below.

TRANSPIRATION AND EVAPORATION

In areas of shallow water table, springs, or seeps, ground water is evaporated and transpired by plants. The quantity of water transpired depends on the plant, density of growth, proximity of the water table to the root zone, soil conditions, and air temperature. Plants having short root systems generally do not consume as much water as those having deep root systems. Plants having short root systems obtain most of their water from the unsaturated soil zone.

In the alluvium of the Arkansas River and its tributary valleys, where the water table is close to the surface, evapotranspiration is considerable. These losses are chiefly due to transpiration by phreatophytes, plants that grow only where ground water is shallow. These plants extend their roots into or just above the water table and literally withdraw water from the zone of saturation.

The principal phreatophyte along the bottom lands of the Arkansas River valley and in some of the tributary valleys and draws is saltcedar (Tamarix gallica), which is noted for its rapid growth and ability to reseed itself readily. The distribution and concentration of saltcedar in Prowers County is increasing each year. Another major phreatophyte in the county is the cottonwood tree. Consumption of ground water by phreatophytes may exceed 3 acre-feet per acre per year in some areas (Gatewood and others, 1950, p. 203). On the basis of the Precipitation-Evaporation Index Method for estimating consumptive use of water for agriculture (Munson, 1960, p. 45), the annual loss of ground water in Prowers County in areas of dense phreatophyte growth is about 2.5 acre-feet per acre.

Some ground water is evaporated along the channels of streams where the ground-water table is near the surface, particularly at springs and seeps.

Evapotranspiration from artesian aquifers is negligible, because most of these aquifers are deep and covered by relatively impermeable formations.

SPRINGS AND SEEPS

Some ground water is discharged from springs and seeps in Prowers County where water-bearing formations have been incised by stream action. Seeps and springs are especially prevalent along parts of the periphery of the Ogallala Formation. Where the water-bearing materials of the Dakota Sandstone have been cut and form steep-walled canyons, water also issues from seeps. Some of the water discharged from seeps enters other formations; however, during the time the water is exposed a part of it is evaporated.

WELLS

One of the principal methods of discharge of ground water in the area is through wells. Most of the water discharges from pumped wells; the remainder discharges by artesian flow. In the alluvial deposits, pumping rates range from a few gallons a minute from stock wells to several thousand gallons a minute from large-capacity irrigation wells. Most of the wells drilled in the Ogallala Formation and sandstone aquifers yield small quantities of water for domestic and stock supplies. A few large-capacity irrigation wells have been drilled into these formations and yield as much as 2,000 gpm.

SUBSURFACE OUTFLOW

Ground water is discharged from Prowers County eastward into Kansas by subsurface outflow. Most of the outflow is through the alluvial deposits in the valley of the Arkansas River. The underflow through the sandstone is north-northeastward into Kiowa County and into Kansas, where the formations dip more steeply beneath the surface.

MOVEMENT OF WATER BETWEEN AQUIFERS

Water moves continuously between aquifers in Prowers County because of the different ground-water gradients and differences in pressure heads resulting from variations in lithologic characteristics of the water-bearing materials and geologic structure. These exchanges of water, however, do not have a profound influence on the overall amount of water in storage.

Water in the Cheyenne Sandstone Member of the Purgatoire Formation, confined under pressure by the overlying Kiowa Shale Member may, in places, discharge upward through sandy beds of the confining layer into the Dakota Sandstone. Likewise, water in the Dakota Sandstone tends to be confined by its own shale beds and the overlying Graneros Shale; however, sandy beds in both formations may allow some upward movement.

Where shallow aquifiers cut across the permeable zones in the Dakota Sandstone, ground water moves from one unit to another. If the Dakota Sandstone is discharging at that point, the shallow aquifer is recharged; but if the piezometric surface of the Dakota Sandstone is below the water table in the shallow aquifer, as it is east of Lamar (line C-C', pl. 4), the sandstone may be recharged. In some areas, water in the Dakota may drain into the alluvial aquifers; in others, small springs discharge from the Greenhorn Limestone and the water seeps into the shallow alluvium.

RECOVERY OF GROUND WATER

Most of the ground water recovered in Prowers County is from drilled wells; only a minor amount is derived from dug wells and springs.

SPRINGS

No springs in Prowers County yield large quantities of water; however, small springs and seeps supply water for livestock and domestic use in a few places. In some areas, spring water entering drainage ditches and canals supplements the surface-water source.

Most springs are of the gravity type; that is, the water discharges by gravity along outcrops of the aquifers. The water of gravity spring "* * * percolates from permeable material or flows from large openings in a rock formation, under the action of gravity, as a surface stream flows down its channel." (Meinzer, 1923, p. 51). The types of gravity springs in Prowers County are (1) depression springswater flows to the surface because the land surface coincides with or intersects the water table, and (2) contact springs—water issues from permeable material overlying material of relatively low permeability, generally where the contact between the materials is exposed along an escarpment. The contact spring is the most common type in the county. Depression springs issue mainly from the Ogallala Formation along Two Butte Creek and its tributaries in the southwestern part of the county. Contact springs issue from several formations, principally in the western part and in areas where the Fort Hays Limestone outcrops north of the Arkansas River. Water issues from the upper part of the Dakota Sandstone in the western part of the county where permeable materials overlie the relatively impermeable sandy shale. The dissection of the Dakota Sandstone in areas cut by erosion expose these permeable zones in numerous places. Many seeps and springs discharge north of the Arkansas River where drainage canals and ditches are cut into the Fort Hays Limestone Member of the Niobrara Formation. The quantity of water discharged at any one point is not great, but collectively, over a large area, the amount is appreciable.

Most springs do not lend themselves to development because of their small yields and intermittent discharge. Much of the spring and seep water in Prowers County is dissipated by transpiration, evaporation, and infiltration.

DUG WELLS

Only a few wells in Prowers County are dug. Most dug wells, ranging from 2 to 6 feet in diameter, are in the shallow alluvial aquifers. Because dug wells generally cannot be deepened more than a few feet below the water table, many fail during extended drought.

DRILLED WELLS

Most wells in Prowers County have been drilled by either rotary drills or percussion (cable-tool) machines. Drilled domestic and stock wells are cased generally with wrought-iron or galvanized-iron casing ranging from 2 to 16 inches in diameter. The greater percentage are 6 inches in diameter. The large-capacity irrigation, industrial, and public-supply wells are cased with wrought iron or galvanized iron ranging from 8 to 36 inches in diameter.

CONSOLIDATED DEPOSITS

Many drilled wells in Prowers County obtain their water from the consolidated rocks of the Dakota Sandstone and Cheyenne Sandstone Member of the Purgatoire Formation. Most of the wells are cased at least down to the top of the water-bearing zones. Well-construction practice requires casing at least to the water-bearing zones in areas where younger consolidated rocks overlie the sandstone aquifers.

Water in the shale formations overlying the aquifers generally is of poor quality, and if allowed to drain into the aquifers, it would contaminate the water of good quality. Generally, when water of poor quality is reached in drilling, careful precautions are taken to seal out the upper zones. Where wells penetrate both the Dakota and the Cheyenne Member and the well is cased only to the top of the Dakota or the casing is perforated adjacent to each sandstone unit, it is quite likely that water from the lower aquifer leaks into the upper. The Cheyenne Sandstone Member of the Purgatoire is very poorly cemented in some parts of the county. Wells in these areas pump large amounts of sand. The sand problem can be eliminated by using well screens or by gravel packing around slotted casing.

UNCONSOLIDATED DEPOSITS

Wells tapping unconsolidated deposits, such as the Ogallala Formation and the alluvium in the Arkansas Valley, are usually cased the full length of the hole to prevent caving. The well should be perforated or screened opposite all water-bearing zones in the hole. Wells opening into the formation only at the bottom of the hole yield less water and are less efficient. The size of casing perforations, especially those in large-capacity irrigation or public-supply wells, is very important because the capacity or even the life of the well may be adversely affected by the perforation size. If the perforations are too large, the fine material may filter through too rapidly and fill the well; if the perforations are too small, they may become so clogged as to retard the entrance of water.

Properly selected well screens or strainers will prevent clogging of perforations and entrance of fine sediments into wells. Well drillers

and pump-sales companies in the area are familiar with these problems and can offer many practical solutions. One of the common practices is to select a slot size that will pass 30 to 60 percent of the waterbearing material. Retention of the coarser particles around the screen forms a natural gravel packing that greatly increases the efficiency of the well and, hence, increases its capacity to yield water.

Gravel-walled wells generally are effective in obtaining large quantities of water from water-bearing materials too fine to screen. Several irrigation and public-supply wells are gravel packed. Gravel-wall construction need not be used in certain water-bearing materials. In much of the alluvium of the Arkansas River and its associated alluvial deposits, the water-bearing deposits contain coarse gravel, and it is generallly unnecessary to use gravel packing.

The most productive large-capacity irrigation wells in the Arkansas Valley are generally those that have been drilled to bedrock and have penetrated the entire thickness of saturated material. Decrening a well will have a greater effect on reducing its drawdown than will increasing the diameter, provided additional water-bearing materials are penetrated.

METHODS OF LIFT

Most of the domestic and stock wells are equipped with lift or force pumps. Most of the pumps on stock wells are operated by windmills, whereas most of the domestic wells are operated by electric motors. Many domestic and stock wells drilled into the deeper sandstone aquifers north of the Arkansas River are equipped with turbine pumps. The flowing domestic wells generally are not equipped with a pump.

Irrigation, industrial, and public-supply wells are equipped mostly with deep-well turbine pumps; a few irrigation wells are equipped with centrifugal pumps. The pipe column of the turbine pumps in large-capacity wells range in diameter from 4 to 12 inches, although most of the columns are 6, 8, or 10 inches. Measured discharges of turbine pumps in the county range from 250 to 3,000 gpm and average 1,200 gpm per well.

About two-thirds of all the irrigation wells in Prowers County are equipped with electric motors. The remainder of the wells are pumped by internal-combustion engines that use butane, propane, natural gas, gasoline, or diesel oil for fuel.

UTILIZATION OF WATER

During the investigation, an inventory was made of all the large-capacity wells and of selected domestic and stock wells. Records of 1,076 wells have been published in a basic-data report on Prowers County (Voegeli and Hershey, 1960). The report contains records

of 669 domestic and stock wells, 148 irrigation wells, 27 public-supply wells, and 12 industrial wells. The remainder of the wells were unused, were used for multiple purposes, or their use wes in doubt.

Irrigation use, the largest, was estimated to be 18,000 and 34,000 acre-feet in 1957 and 1958, respectively. The second largest use is industrial; the city of Lamar is the principal industrial user. The total annual use of ground water for public supplies is about 3,000 acre-feet or 3 mgd (million gallons per day), for domestic use about 1,000 acre-feet or 1 mgd, and for livestock use less than 500 acre-feet. The total use of water varies considerably from year to year, depending largely on the amount withdrawn for irrigation. Total withdrawal ranges roughly from 30,000 to 40,000 acre-feet per year.

DOMESTIC SUPPLIES

Most of the domestic wells in Prowers County tap one of the following water-bearing formations: the Ogallala Formation, the shallow alluvium of the streams tributary to the Arkansas River, and the Dakota Sandstone. Some domestic water is obtained from the Arkansas River alluvium; however, the chemical quality of this water is relatively poor, and the aquifer is not considered a good source of domestic supply.

STOCK SUPPLIES

Stock-water supplies are obtained from all the aquifers in Prowers County. The depth to water in stock wells ranges from a few to several hundred feet. In a few places, stock supplies are supplemented by spring water. Most of the stock wells are equipped with lift pumps operated by windmills.

PUBLIC SUPPLIES LAMAR

Lamar is supplied by 21 wells owned by the city. The wells tap the alluvium of Clay Creek. They range in depth from 44 to 90 feet and in yield from 100 to 550 gpm. The static-water levels range from 31 to 60 feet below the land surface, and drawdown in pumped wells is usually less than 10 feet. Most of the wells are cased with 16-inch steel casing, and all are equipped with turbine pumps powered by electric motors. During the summer, when maximum quantities of water are withdrawn, as many as nine pumping plants may be in operation; during periods of minimum withdrawal, one to three pumping plants are operated. It has never been necessary to pump all the wells simultaneously to satisfy the water requirements of the city. The chemical quality of the water meets most of the standards set up by the U.S. Public Health Service. (See section on "Quality of water," p. 41.)

HOLLY

Holly is supplied by three wells owned by the city. The wells, drilled into the Dakota Sandstone and Cheyenne Sandstone Member of the Purgatoire Formation, are reported to range in depth from 625 to 656 feet. The static-water level of one of the wells is 30 feet below the land surface; the other levels probably are about the same depth. The wells are equipped with turbine pumps powered by electric motors. The chemical quality of the water is good. (See p. 46.)

GRANADA

Granada has five wells; two presently are in use. Four of the five wells were drilled at the Japanese Relocation Center (Camp Amache) in 1942, and during World War II they reportedly supplied vater for as many as 10,000 people. At the present time (1962), only one of the wells at Camp Amache is being used. The fifth well, drilled in 1934 adjacent to the main line of the railroad, also is being used. The wells, which tap the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation, are about 750 feet deep. One well is reported to yield 112 gpm. The well adjacent to the railroad will flow, although its static-water level is less than 1 foot above the land surface. The level in the well at Camp Amache is 40 feet below the land surface. The pumping level in the flowing well is 181 feet, and the pumping level in the well at Camp Amache is 251 feet. The wells are equipped with turbine pumps powered by electric motors.

The water from the wells in the Granada system is chemically suited for most uses.

WILEY

Wiley has two municipal wells drilled into the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation. The two wells are reported to have a combined yield of 130 gpm. The first well, drilled in 1954, is 552 feet deep, cased to 425 feet with steel casing, and is equipped with a turbine pump powered by an electric motor. The second well, drilled in 1956, is 705 feet deep and is equipped with a turbine pump powered by an electric motor; it is reported to yield at least 100 gpm.

The chemical quality of the water from the two wells is not as good as that from most other wells drilled into the Dakota Sandstone and Cheyenne Sandstone Member of the Purgatoire Formation elsewhere in the county. The natural radium content of the water is high. (See p. 50.)

BRISTOL

The community of Bristol is supplied by a single drilled well (22–44–24acb) that is reported to be 569 feet deep and obtains water from the Dakota Sandstone. The static-water level in the well is reported

to be 180 feet below the land surface. The well is equipped with a turbine pump and is powered by an electric motor. A chemical analysis of a sample of its water is shown in table 3.

INDUSTRIAL SUPPLIES

The only significant consumer of ground water for industrial use in Prowers County is the city of Lamar, which obtains water from the Arkansas River alluvium for use as a coolant in its thermal generating plant. Water is obtained from 8 wells ranging in depth from 38 to 60 feet. The wells are equipped with turbine pumps and are powered by electric motors. Pumping levels range from 22 to 36 feet. Prior to the use of diesel locomotives, the Atchison, Topeka and Santa Fe Railway Co. had several wells in Prowers County, which provided water for steam locomotives. These wells are now either backfilled or otherwise out of use.

IRRIGATION SUPPLIES

The number of irrigation wells in Prowers County has increased sharply since 1950. In 1958 there were about 160 large-capacity irrigation wells in the county. Irrigation wells are used as supplementary sources to surface-water supplies and as principal sources of water for crops. More than 95 percent of the irrigation wells in the area are in or near the Arkansas Valley.

Numerous attempts to develop large-capacity irrigation wells in areas other than the valley generally have met with little success, except in an area about 18 miles south of Holly where the Willhite Bros. have obtained large quantities of water from wells that tap the Ogallala Formation, the Dakota Sandstone, and the Chevenne Sandstone Member of the Purgatoire Formation.

Large yields also have been obtained in the extreme northeastern part of the county from wells tapping the Ogallala Formation. Some wells have failed to obtain adequate quantities of irrigation water outside of the Arkansas Valley because they were drilled into formations incapable of producing large quantities of water. Others have been drilled into formations capable of producing large quantities of water, but have failed because they (1) did not penetrate the full thickness of the aquifer, (2) were improperly constructed, or (3) were improperly developed.

Yields from irrigation wells measured in Prowers County ranged from 265 to 3,050 gpm and averaged 1,200 gpm. Drawdown ranged from 2 to 28 feet. Measured yields generally were slightly greater, and measured drawdowns slightly less, than the average seasonal yield and drawdown because most of the measurements were made about 15 minutes after the pumps were started. The pumping rate

generally decreases and the drawdown increases after pumping for extended periods.

The amount of water pumped is small compared to the amount of water stored in the alluvium of the Arkansas River and its associated deposits (about 1 million acre-feet). Even during a year of heavy pumping, such as 1958, when 34,000 acre-feet was withdrawn, the total amount of water pumped from these deposits is less than one-twentieth of the water in storage. The aquifer is not being depleted because the recharge to it is at least equal to the withdrawal rate. Part of the water pumped is consumed by evapotranspiration, or lost by surface runoff; the remainder of the water spread on the fields recharges the aquifer.

POSSIBILITIES OF ADDITIONAL DEVELOPMENT OF LARGE SYPPLIES OF WATER FROM WELLS

Additional large supplies of ground water possibly can be obtained from wells tapping the untested sandstone aquifers in the western part of the county south of the Arkansas River and from those tapping a combination of the Ogallala Formation, Dakota Sandstone, and Cheyenne Sandstone Member of the Purgatoire Formation in the southeastern part. Smaller irrigation wells can be obtained in those areas in the northeastern part of the county that are underlain by thick deposits of the Ogallala. It is unlikely that large-capacity wells could be developed from unconsolidated deposits south of the Arkansas Valley between the Prowers-Bent County line eastward to R. 42 W. The deeper sandstone deposits in this area may be capable of producing large quantities of water, but their potential has not been explored.

QUALITY OF GROUND WATER

The water in all the major aquifers in Prowers County is of a quality that may be used for some economic purpose. Some of the water suitable for stock and irrigation supplies may not be desirable for domestic use because of its relatively poor chemical quality, whereas water suitable for domestic and public supplies generally is suitable for most uses.

The chemical quality of water from an aquifer is a good indicator of the material through which the water has migrated or has been stored. Many formations in Prowers County contain mineral constituents that are readily dissolved by ground water. The dissolved solids in the ground water consist chiefly of carbonates, bicarbonates, chlorides, sulfates, and nitrates of calcium, magnesium, sodium, potassium, and traces of iron, manganese, and other substances. The residue after a natural water has evaporated consists of rock materials, and may also include some organic material and some water of crystallization.

The specific conductance, the measurement of the ability of the water to conduct an electrical current, is a rough measure of the dissolved-solids content of water. In general, the specific conductance increases as the dissolved-solids content increases. The ratio of dissolved solids to specific conductance is approximately 0.64 for most natural water, but may range from 0.6 to more than 0.9; the ratio increases somewhat as the dissolved-solids content increases. The ratio for water from unconsolidated deposits is somewhat higher than that for water from consolidated deposits.

The chemical constituents of water analyzed by the Geological Survey are reported in parts per million (ppm). A part per million is a unit weight of a constituent in a million unit weights of water.

QUALITY OF WATER IN RELATION TO USE

Samples of water analyzed were collected from 50 wells—20 domestic, 16 irrigation, 8 public supply, and 6 stock; 1 sample was from an unused spring. The results of the analyses are shown in table 3. The quality-of-water requirements for industrial supplies are not discussed because industrial supplies are few, and the requirements vary widely for different industries.

PUBLIC AND DOMESTIC SUPPLIES

Water for acceptable public and domestic supplies must conform to certain standards because of the physiological effects on human beings or because of esthetic or economic reasons.

In 1961, the Advisory Committee on Revision of U.S. Public Health Service 1946 Drinking Water Standards recommended certain standards for public and domestic water supplies (U.S. Public I^{*}ealth Service, 1961, p. 935). The committee consisted of representatives of private and governmental institutions, and some of the recommendations are as follows:

The chemical substances shown below should not be present in ε water supply in excess of the listed concentrations where, in the judgment of the reporting agency and the certifying authority, other more suitable supplies are or can be made available.

c	oncentration
Substance	(ppm)
Arsenic (As)	0.01
Chloride (Cl)	250. 0
Iron (Fe)	. 3
Manganese (Mn)	. 05
Nitrate (NO ₃) ¹	45 . 0
Sulfate (SO ₄)	250.0
Total dissolved solids	500.0

¹In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

The committee recommended, concerning the presence of fluoride in drinking water: "When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit" as shown below:

Annual average of maximum daily air temperatures ¹ (°F)	Recommended limits of fluoride concentration (ppr1)				
	Lower	Optimum	Upper		
50.0-53.7 53.8-58.3 58.4-63.8 63.9-70.6 70.7-79.2 79.3-90.5	0. 9 . 8 . 8 . 7 . 7 . 6	1. 2 1. 1 1. 0 . 9 . 8 . 7	1. 7 1. 5 1. 3 1. 2 1. 0		

¹ Based on temperature data obtained for a minimum of 5 years.

"Presence of fluoride in average concentrations greater than two times the optimum values as shown above shall constitute grounds for rejection of the supply," the committee ruled.

Much water used in the county does not conform to the stendards; however, many residents evidently develop a tolerance to the various constituents that exceed recommended limits.

Quantities of iron exceeding 0.1 ppm in natural water exposed to air usually will precipitate as a reddish sediment which stains clothing and porcelain. The disagreeable taste imparted by excessive iron may be removed from most waters by simple aeration and filtration. If the iron content is unusually great, the water may have to be treated with lime or by some other method.

Concentrations of sulfate in excess of 250 ppm may cause a laxative effect, especially when in solution with magnesium or sodium. However, many persons drinking water with a high sulfate content develop a tolerance through continued use. In many of the natural waters of Prowers County, concentrations of sulfate range from 59 to 3,310 ppm. The sulfate is derived chiefly from the contact of the ground water with formations containing an abundance of gyp3um.

Large concentrations of chloride may indicate the water is contaminated from an organic source, but, because the sources of chloride from natural sources are many, its presence is not necessarily proof of contamination. If the chloride content is not great enough to impart a salty taste, the constituent has little effect on the suitability of the water for domestic use.

IRRIGATION SUPPLIES

Both soils and crops may be adversely affected by excessive concentrations of salts in irrigation water. Salinity of irrigation water, the proportion of sodium to calcium and magnesium, and concentra-

tions of other constituents are important factors affecting the growth of plants.

High concentrations of dissolved salts in irrigation water may increase the amount of salts in soil. In poorly drained soils, when a salt solution becomes too concentrated for plants to get enough fresh water, or if the salt concentration is high enough to result in a toxic condition, the growth of plants is affected. The tendency of irrigation water to accumulate salts in the soil is referred to as the "salinity hazard" of the water. Specific conductance is used as an index of salinity hazard.

Soil structure can be adversely affected by high concentrations of sodium relative to concentrations of calcium and magnesium in irrigation water. Calcium and magnesium tend to flocculate soil particles, and sodium tends to deflocculate them. Flocculation loosens soil and makes it more permeable and allowing greater circulation of water and air. Deflocculation packs soil and prevents easy entry of water and air. The effects on soil caused by high concentrations of sodium in irrigation water is referred to as "sodium hazard." An index used for predicting sodium hazard is the SAR (sodium-adsorption-ratio), which is defined by the equation

$${\rm SAR}{=}\frac{Na^{+1}}{\sqrt{\frac{Ca^{+2}{+}Mg^{+2}}{2}}}$$

where, Na^{+1} , Ca^{+2} , and Mg^{+2} are in equivalents per million ($^{\text{U}}$.S. Salinity Laboratory Staff, 1954, p. 72).

Many constituents in irrigation water in Prowers County are beneficial to plants. However, if the quantity of some of these constituents is excessive, normal growth of the plants is affected. High concentrations in soil solutions of such constituents as sodium, calcium, magnesium, chloride, sulfate, and bicarbonate have been reported to be associated with toxic reactions in some plants (U.S. Salinity Laboratory Staff, 1954, p. 61–63). Normal growth of plants is facilitated by the proper amount of boron, usually less than a few parts per million; however, when the quantity of boron is excessive, plants are injured (U.S. Salinity Laboratory Staff, 1954, p. 81).

There are several methods for classifying irrigation water so that the long-term effect on soil productivity may be forecast. The one used here is that of the U.S. Salinity Laboratory Staff (1954, p. 75–81). In this method, the water is classified by salinity hazard, sodium hazard, boron concentration, and the amount of residual sodium carbonate. Only the classification based on salinity and sodium hazards will be discussed here. The other classifications seem to be of little importance in Prowers County, according to available data.

Salinity hazard and sodium hazard were determined from a diagram (fig. 14), which is interpreted by the U.S. Salinity Laboratory Staff (1954, p. 80) as follows:

Salinity hazard.—LOW-SALINITY WATER (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

MEDIUM-SALINITY WATER (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

HIGH-SALINITY WATER (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for selinity control may be required and plants with good salt tolerance should be selected.

VERY HIGH-SALINITY WATER (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt-tolerant crops should be selected.

Sodium hazard.—The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

LOW-SODIUM WATER (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

MEDIUM-SODIUM WATER (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

HIGH-SODIUM WATER (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

VERY HIGH-SODIUM WATER (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Each class in the diagram includes a wide range of salinity. In evaluating a particular water, the relative position of the point within the class should be considered and not the class alone. Water having a specific conductance of 800 micromhos is much better than one of 2,000 micromhos, even though both are classed as C3.

The designers of the diagram point out that:

In the classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate,

drainage, quantity of water used, climate and salt tolerance of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality.

Although water from irrigation wells in Prowers County has not affected the growth of crops adversely, water from some other wells probably would be detrimental to plant growth. Water from some wells tapping the Dakota has both a high salinity and a high sodium hazard, whereas the water in the Ogallala probably is suitable for irri-

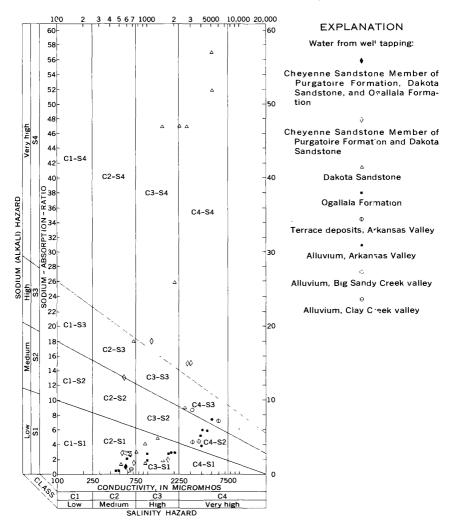


FIGURE 14.—Classification of irrigation water in Prowers County. Diagram after U.S. Salinity Laboratory Staff (1954, p. 80).

gation of most crops. The quality of water from the Dakota and other formations varies so greatly that analyses should be made before it is used on crops. Soil and drainage are sufficiently favorable in most places that substandard water may be used if water of better quality is not available.

STOCK SUPPLIES

The chemical quality of ground water in Prowers County is suitable for most livestock. Livestock tolerances to dissolved solids are extremely variable and range from 3,000 to 15,000 ppm (Rainwater and Thatcher, 1960, p. 269). Some ground water in the county may have salinity concentrations that are greater than that considered by some authorities as suitable for poultry and pigs. In general, the quality of ground water in Prowers County is acceptable for beef cattle and horses; however, there are reports of isolated occurrences of water of extremely bad quality, which livestock have refused to drink. This water is from wells drilled into and receiving minor quantities of water from an all-shale formation.

PROTECTION OF SUPPLIES

The analyses of the water samples reported in table 3 do not show bacterial content. Water may contain mineral constituents that impart an objectionable odor or taste and yet be free from harmful bacteria and safe to drink. On the other hand, water may be cool, clear, and pleasant to the taste and yet contain harmful bacteria. To avoid pollution and contamination, wells should be properly sealed above the water level. Proper seating of casing and correct placement of packers may eliminate pollution and contamination.

The chemical quality of ground water may be affected by leakage and mixing of water of poorer quality from another formation. Formations containing water of poor quality should be sealed off.

QUALITY IN RELATION TO WATER-BEARING FORMATIONS

The quality of water typical of the principal water-bearing formations in Prowers County is shown in table 3.

WATER DERIVED FROM WELLS TAPPING BOTH THE CTEYENNE SANDSTONE MEMBER OF THE PURGATOIRE FORMATION AND THE DAKOTA SANDSTONE

Eight samples of water were collected from wells tapping both the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation. Hardness ranged from 37 to 757 ppm; however, 200 ppm was exceeded in only half the samples. Three of the samples had a fluoride content in excess of the upper limit (1.7 ppm) recommended by the U.S. Public Health Service (1961) as safe for drinking

water. The quality of water in both the Cheyenne Member and the Dakota varies considerably from place to place.

DAKOTA SANDSTONE

Eighteen samples of water were collected from wells tapping the Dakota Sandstone. Hardness ranged from 10 to 650 ppm; however, 220 ppm was exceeded in only six of the samples. The quality of water from the Dakota Sandstone differs from place to place. In some places, the iron content is great enough to stain laundry and household plumbing fixtures. The chemical quality of the water of the Dakota Sandstone in many places does not meet the recommended standards for public and domestic water supplies; however, people in the county using substandard water from the Dakota Sandstone report no adverse effects.

OGALLALA FORMATION

Seven samples indicate that water from the Ogallala Formation generally is the best quality of any in Prowers County. Compared with water from other sand and gravel deposits, that from the Ogallala contains substantially less sodium and sulfate. The iron content is low compared to that of water from the sandstone aquifers. None of the samples had less than 200 ppm hardness; only two, however, exceeded 270 ppm.

ALLUVIUM AND ASSOCIATED DEPOSITS OF THE ARKANSAS VALLEY

The dissolved solids of 11 water samples from the alluvium of the Arkansas Valley and associated deposits ranged from 1,360 to 5,340 ppm. The sodium content ranged from 187 to 810 ppm, and the sulfate content ranged from 756 to 3,310 ppm. The samples suggest that the water has a very high salinity hazard and a low to high sodium hazard (fig. 14).

OTHER FORMATIONS

Mixed water from the Cheyenne Sandstone Member of the Purgatoire Formation, Dakota Sandstone, and Ogallala Formation was sampled in one area only; the water is of good quality for most uses. The quality of such mixed water would, of course, differ in other areas—depending upon the amount and quality of water contributed from each unit.

The quality of water in the alluvium of Clay Creek in its lower reaches seems to be far superior to that in the alluvium of Big Sandy Creek. The differences in bedrock of the two stream valleys is one of the principal reasons for the difference in quality. The alluvium of Clay Creek rests chiefly on the Dakota Sandstone, which normally

[Results in parts per million except as indicated. Analyses by U.S. Geol. Survey. Geologic source: Kpc, Cheyenne Sandstone Member of Purgatoire Formation; Kd, Dakota Sandstone; Kc, Carille Shale; Kn, Niobrara Formation; To, Ogallala Formation; Qt, terrace deposits; Qal, alluvium of Arkansas River; Qal, B, alluvium of Big Sandy Creek; Qal, C, alluvium of Clay Creek. Use: D, domestic: I, irrigation; N, none; PS, public supply; S, stock] Table 3.—Chemical analyses of water from typical wells in Prowers County, Colo.

	Use		SS S	S D _L D, S	D, s I s	n I D, s
oits	Sodium-a bsorption-ratio		47. 47. 7 47. 6 26. 3. 6	11 75 75 4.4 52 4.4 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5	∞ ಬ.ಸ. ಚ.4.	4.4.7.1. 7.7.1.0
	Percent sodium		88288	53883		4 488
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ті 'әә	Specific conductant	880 960 960 109	000 000 000 000 000	9250 920 920 920 920 920 920 920 920 920 92	721 756 000	8588
ness CO ₃	Noncarbonate	528 167 167 60 1,	489 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	, 300 2, 4, 7, 8	,310,4	1, 010 3, 1, 020 3, 1, 240 3, 398 1,
Hardness as CaCO ₃	Calcium, magnesium	66888	681 120 170 46	255 129 129 189	16 179 .540	170 190 550 650
(O)	Dissolved solids (resi evaporation at 180				478	-144
(*(Orthophosphate (PC				0.0	
	Vitrate (NO ₃₎	7-8-0-4 0-4-0	6 6 7	2.1.9 7.1.0 0.0	3,20	7.50
	Fluoride (F)	2841	11.21.1	000140	2.0 1.4 6.	1100
	Chloride (Cl)	8881	512 55 55 54	85525 4	7.0 18 196	2288
	Sulfate (SO4)	2827	390 390 390 290 290	768 910 040 910 152	100	630 590 010 585
	Carbonate (CO3)		300	11111	- 6	<u> </u>
(Bicarbonate (HCO3	186 250 226	234 338 286 428	322 465 466 258 327	338 241 274	205 209 376 307
	Potassium (K)	&4.64 &0.00	ಡ಼ಬ!ಬಡಿ.4 ದಯಯ4ಯ	2000 2000 2000 2000 2000 2000 2000 200	4.0.8	7.0 6.6 12
	(aN) muibos	178 87 118 32	524 322 650 250 420	396 1, 170 1, 200 408 139	160 88 88	365 362 464 110
	Magnesium (Mg)		80 1.5 122 5.8 5.8	34 111 182 182 18	2. 4 18 126	69 158 158
	Calcium (Ca)	¥22 88	141 268 4.8 8.8 8.8	85228 8	2, 24 8 4	357 296 360 140
	Manganese (Mn)				0.00	
	tron (Fe)			9.0	1.4 .30 .14	. 04
	(IA) munimulA				6 0.1	
	Silica (SiO2)		0=10010	1000100=	oó	<u> </u>
\	Temperature (°F)	11–26–57 58 11–25–57 58 11–14–57 57	82828	65 65 59 61	57	 %8888
	Date of collection		$\begin{array}{c} 11-13-57 \\ 10-26-57 \\ 2-12-58 \\ 2-12-58 \\ 2-13-58 \end{array}$	3- 6-58 3- 6-58 2-13-58 10-17-57 3- 5-58	7-23-58 8-11-58 6- 5-58	11-14-57 3- 5-58 10-17-57 10-17-57
	Geologic source	To To To	Qal, B Kd Kd Kn	Kd Kd Kd Qt	Kd Kd Qal	Qt Qal Kd
	Depth (feet)		540 800 860 600	765 537 413 140 765	632 569 70	202828
	Location		21-45-8ddd	21-47-24ccd 32dcd 33ccc 22-42-33abb	22-43-16abb 22-44-24acb 34ccc	22-45-14cdb

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22-46-14agal 15bbb 23dddl 35bcb.	22-47-8bad 3 8bdd 3 8bdc 31cbcl	23–42–15daa. 18ebb. 25aad. 30ddd.	23-43-5cacl 23-44-3cdd 10bad 12bdd 4	23-45-14beg 23-46-2dba 23-47-4aca 4dba	24-42-3aab 24-44-18ddc 25-42-36cc 26-41-4cc 26-41-4cc	4bcb	Sample collected from the Arkansas River at Lamar at a point 450 ft up-stream from the U.S. Geol. Survey gaging station in the SWy, MS-SSE, R. 46 W.

⁴ Contains 0.3 ppm strontium. ¹ Spring. ² Contains 1.2 ppm strontium. ³ Contains 1.6 ppm strontium. imparts little mineralization to water. The alluvium of the Big Sandy rests chiefly on the Carlile Shale and Niobrara Formation, which normally impart much mineralization to water. Analysis of only one sample of each body of water, however, is not considered representative. Analysis of several samples would be more conclusive because alluvial deposits generally contain water having a wide range in chemical quality.

NATURAL RADIOACTIVITY

Seven of the samples of water collected for chemical analyses were also analyzed by the Geological Survey to determine the concentration of uranium and radium and the amount of gross beta-gamma activity. The beta-gamma activity, and the radium and uranium content of water from selected wells are shown in table 4. Six of the samples were collected from wells tapping both the Cheyenne Sandstone Member of the Purgatoire Formation and the Dakota Sandstone; the other was collected from the Arkansas River. The collection and analyses of these samples is part of the reconnaissance phase of a study by the U.S. Geological Survey of the occurrence and behavior of radioelements in the natural waters of the Nation. One of the primary objectives of a study now being made is to ascertain the natural radioactive background of public-water supplies.

Natural radioelements, in varying quantities, are found in all surface and ground water. Radioactive rocks and minerals are the chief source of radioactivity in ground water. Ground water in contact with radioactive rocks assimilates radioelements, which become an inherent part of the water. The amount of radioelements in ground water differs from aquifer to aquifer and even within an aquifer.

The maximum absolute beta-gamma activity in the sampled water was 36 $\mu\mu$ c per l (micromicrocuries per liter) from the Arkansas River, but the activity may be as great as 110 $\mu\mu$ c per l in water from well 22–47–8bbd (table 4). A micromicrocurie is that quantity of a radioactive substance that undergoes 2.22 disintegrations per minute. The "less than" symbol used in reporting values of beta-gamma activity indicates that the counting rate of the sample was not greater than probable fluctuations in the cosmic-ray background measured by the instruments used in determining the activity. For example, a value reported as less than 23 $\mu\mu$ c per l would indicate that the analyst was less than 95 percent certain a significant amount of activity was present and more than 50 percent certain that the activity was less than 23 $\mu\mu$ c per l. It is not possible to report exact values for very low levels of radioactivity because of the purely random nature of the radioactive-disintegration process and the presence and random nature

of the cosmic-ray background. The radium content of the ground water sampled ranged from 0.8±0.2 to 14±2 μμc per 1. Uranium ranged from 0.3±0.1 to 1.5±0.2 micrograms per liter. The disintegration of uranium is extremely slow, and it is impractical to measure the rate in the same manner as the disintegration of radium is meas-Therefore the quantity of uranium in a water sample is expressed in units of weight per liter.

Table 4.—Beta-gamma activity, radium and uranium content of water from selected wells

[Geologic source: Kpc, Cheyenne Sandstone Member of the Purgatoire Formation; Kd, Dakota Sandstone; To, Ogallala Formation]

Well	Owner	Geologic source	Date sampled	Beta- gamma activ- ity (μμα per l)	activity	(Ra) (µµc per	Uranium² (U) (micro- grams per liter)
22-47-8bad 22-47-8bbd 22-47-8bbd 23-44-12bdd 24-44-18ddc	Town of Wileydodo Town of Granada.	Kpc, Kddododododo	June 6, 1958. Jan. 18, 1957. June 6, 1958. do Oct. 2, 1958.	<108 <110 <84 32	Aug. 5, 1958_ Mar. 5, 1957_ Aug. 5, 1958_ Aug. 6, 1958_ Oct. 27-28,	11 ± 2	0.7±0.1 .4± .1 .6± .1 .3± .1
26-42-4bcb	C. E. Willhite	Kpc, Kd,	do	<18	1958, do	.8± .2	1.5± .2
Water from the Arkan- sas River at Lamar ³ .		To.	Jan. 31, 1960	36±6	Apr. 28, 1960	.1± .1	75± .8

¹ Nearly all the radium values reported represent radium isotope 226. According to the current recommendations for concentrations of radium 226 in drinking water, those that exceed, on the average, 3 μμc per l (1 micromicrocure=10-12 curie) for 1 year shall constitute grounds for rejection of the supply (U.S. Pub. Health Service, 1961, p. 944).

¹ Values cited are far below maximum permissible concentrations for uranium as reported in "Recommendations of the International Commission on Radionical Protection, Supplement 6." mubils had by the

dations of the Interntional Commission on Radiological Protection, Supplement 6," published by the British Institute of Radiology.

3 Sample collected 450 feet upstream from the U.S. Geol. Survey gaging station in SWMNEM sec. 30, T.

Every effort should be made to prevent the accumulation of dangerous quantities of radioelements in the human body. Radioelements may enter the body by way of food and water, through the air breathed, and through the pores of the skin. Some radioelements, such as radium 226, radium 224, and strontium 90, are not readily eliminated from the body. There is no agreement on the exact amount of radiation that is harmful to the individual; however, the limits cited are conservative, are derived from the best information now available, and may be adjusted upward or downward as more accurate data become available (U.S. Public Health Service, 1961, p. 936).

The concentration of radium in the samples collected was below the recommended limits, except for that in the sample of water derived from the public-supply wells at Wiley and from irrigation well 24-44-18ddc.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Rocks that crop out in Prowers County range in age from Permian to Recent. The Permian and the underlying rock units are at great depth throughout most of the county; these rocks probably contain only meager quantities of highly mineralized water. stone of Triassic age is the stratigraphically lowest unit likely to produce fresh ground water. The sandstone of Triassic age has not been penetrated by a water well in Prowers County, and, therefore, its possibilities as an aquifer remain unproven. A few wells obtain water from sandstone lenses in the Morrison Formation of Late Jurassic age. The Chevenne Sandstone Member of the Purgatoire Formation of Early Cretaceous age is the best aquifer that occurs at considerable depths in most parts of the county. The Dakcta Sandstone of Early Cretaceous age is the shallowest consolidated formation capable of producing fresh water. The Dakota Sandstone is the most extensive aquifer and is capable of supplying domestic and stock water in nearly every part of the county. The surficial material overlying the Upper Cretaceous rocks provides a reservoir for fresh water in many parts of the county. Large-capacity wells, for the most part, tap surficial material comprising the alluvium and the Ogallala Formation.

PERMIAN SYSTEM

In Prowers County rocks of Permian age crop out only on Two Buttes and immediate vicinity. The exposed Permian rocks consist of three units. In ascending order they are: the sandstone of Whitehorse age, Day Creek Dolomite, and the Taloga Formation (of Cragin).

SANDSTONE OF WHITEHORSE AGE

The sandstone of Whitehorse age is the oldest formation that crops out in Prowers County. The uppermost part of the formation crops out only in one small area southeast of Two Buttes dome in the S½ sec. 31, T. 27 S., R. 45 W. The beds consist chiefly of buff to red fine sandstone and red shale in the Two Buttes area.

The sandstone of Whitehorse age underlies all Prowers County, and beds of equivalent age have been identified in oil prospects in all adjacent areas. The sandstone of Whitehorse age is about 30 feet thick at the outcrop at Two Buttes according to Sanders (1934, p. 868). Elsewhere in the county, where the formation has been fully penetrated by oil prospects, thicknesses ranging from 200 to 300 feet have been reported.

No wells obtain water from the sandstone of Whitehorse age in Prowers County.

DAY CREEK DOLOMITE

The Day Creek Dolomite crops out only in one small area southeast of Two Buttes dome, where it is underlain by the sandstone of Whitehorse age and overlain by the Taloga Formation (of Cragin). At Two Buttes, the Day Creek consists of light-gray dense dolomite. Elsewhere in the county, where the Day Creek has been penetrated by deep oil prospects, the unit consists of dolomite, anhydrite, or gypsum.

The Day Creek Dolomite underlies all of Prowers County. The unit is 12 feet thick at Two Buttes and ranges in thickness from about 10 to 60 feet elsewhere in the county.

No wells obtain water from the Day Creek Dolomite.

TALOGA FORMATION (OF CRAGIN) (1897)

The uppermost beds of rocks of Permian age in Prowers County are represented by the Taloga Formation (of Cragin). These rocks crop out in several small areas on the sides of Two Buttes and in areas southwest and southeast of Two Buttes north of the Baca County line (pl. 1). The beds consist chiefly of red to buff shale, siltstone, and sandy shale containing thin beds of hard sandstone. In a few places the beds are calcareous and contain streaks of white calcium carbonate. The sandstone beds are prominent because they are a vivid brick red.

The Taloga Formation underlies all Prowers County, and beds of equivalent age have been identified in oil prospects in all adjacent areas. The Taloga is reported to be 204 feet thick in the vicinity of Two Buttes (Sanders, 1934, p. 863), where the formation is exposed between the overlying Triassic formations and the underlying Day Creek Dolomite. Elsewhere in the county, oil tests show that the thickness of the Taloga generally does not exceed 100 feet; however, it is reported to be as much as 400 feet in some places. The formation appears to thin to the northeast.

No wells obtain water from the Taloga Formation in Prowers County. The formation lies at great depth in most parts of the county and its lithologic characteristics indicate that the unit probably would not produce water in useful quantities.

TRIASSIC SYSTEM

DOCKUM GROUP

Rocks of Late Triassic age are exposed in southeastern Colorado, northwestern Oklahoma, and northeastern New Mexico. They have been dated paleontologically by McLaughlin (1954, p. 85), Stovall (Schoff and Stovall, 1943, p. 50), and others. In Union County,

N. Mex., Parker (1933) divided the Triassic into three units: Dockum Group, Sloan Canyon Formation, and Sheep Pen Sandstone in ascending order. Stovall (Schoff and Stovall, 1943, p. 45) revised Parker's classification by applying the name Dockum Group to the entire threefold division. Stovall retained the names for the upper two units and designated Parker's Dockum Group as the unnamed unit. In this report rocks of Triassic age underlying the county are considered to be a part of the Dockum Group as established by Stovall. It seems that the Triassic rocks of Prowers County consist of the unnamed unit and the Sloan Canyon Formation of Stovall. The Sheep Pen Sandstone of Stovall does not occur in Prowers County.

Triassic rocks are exposed on the highest part of the Two Buttes dome and in an area southwest, southeast, and directly east of Two Buttes (pl. 1). The Dockum Group underlies all but the nor heastern part of the county (fig. 15). The Triassic rocks are thickest along the Bent County line south of the Arkansas River. The thickness of the Triassic rocks ranges from 150 to 540 feet in the county.

The unnamed unit in Prowers County consists chiefly of sandstone, but locally it contains thin beds of conglomerate, limestone, and shale. The sandstone is usually poorly sorted and ranges from fine to medium grained. The Sloan Canyon Formation of Stovall consists chiefly of siltstone, sandstone, and limestone.

No water wells have been drilled into the Dockum Group in Prowers County. Where the unit is thick and relatively close to the surface, some water might be obtained from wells that tap thick sequences of sandstone. The chemical quality of the water is unknown.

JURASSIC SYSTEM

UPPER JURASSIC SERIES

Only Upper Jurassic rocks occur in southeastern Colorado. The Upper Jurassic Series, as used in this report, refers to the sandstone and shale units beneath the Purgatoire Formation and above the Triassic rocks. Rocks of Jurassic age underlie all of Prowers County except the southeastern part (McKee and others, 1956, pl. 3; see also fig. 15, this report). The rocks were subdivided by Oriel and Mudge (1956, p. 21) into three units: (1) The Entrada Sandstone at the base, (2) the middle unit of Jurassic age, and (3) the Morrison Formation. The middle unit of Jurassic age and the Morrison Formation were mapped in the field as a unit, and are shown on the geologic map (pl. 1) as a unit.

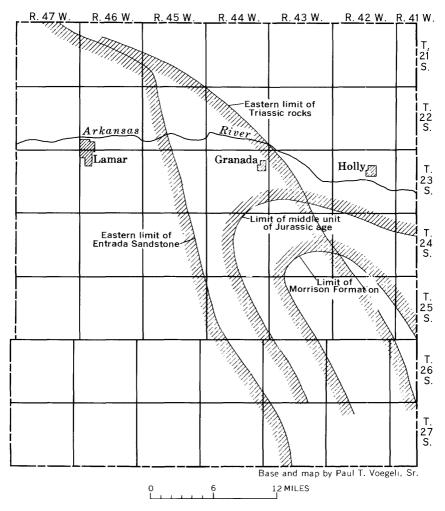


FIGURE 15.—General limits of the Triassic and Jurassic Formations.

ENTRADA SANDSTONE

The name "Entrada Sandstone" as used in this report, refers to the sandstone beneath the middle unit of Jurassic age and above the Triassic rocks. It is underlain conformably in Prowers County by the Dockum Group of Triassic age.

The Entrada Sandstone along Two Butte Creek was first described by Gilbert (1896a, p. 817), who referred to it as unit 4 of the local section along Two Butte Creek. Sanders (1934, p. 865) considered Gilbert's unit to be of questionable Triassic age, in part because he believed that the unit represented a lens in the Morrison Formation.

Other workers in the region, Parker (1934, p. 1544) and Schoff and Stovall (1943, p. 56), have shown rather conclusively that the Entrada is not a lens in the Morrison, but a separate unit comparable to the Exeter Sandstone of Lee (1902, p. 45) and Stovall (Schoff and Stovall, 1943, p. 51). Baker, Dane, and Reeside (1947, p. 1664) and Oriel and Mudge (1956, p. 21) also recognized that the Entrada extends into southeastern Colorado. The term is now used in southeastern Colorado by the U.S. Geological Survey.

Character.—In its area of outcrop along Two Butte Creel (pl. 1), the Entrada is chiefly a massive white to buff crossbedded fine- to medium-grained sandstone. Where the Entrada Sandstone is underlain by sandstone of the Dockum Group, differentiation of the two units on the basis of lithologic characteristics is nearly impossible; much more work remains to be done if a true break is to be established between the formations. Oriel and Mudge (1956, p. 20) point out this problem and suggest:

The following criteria, although meager, may be of aid locally:

- 1. Locally, color can be used. The Entrada Sandstone is gray, white, or cream in most places, whereas the beds of sandstone in the Dockum Group are mainly orange, red, or pink.
- 2. The Entrada Sandstone is coarser grained in many places than sandstone in the upper part of the Dockum Group.

Distribution and thickness.—The Entrada Sandstone crops out along Two Butte Creek southeast of Two Buttes dome (pl. 1), and has been penetrated in oil prospects in the western part of the courty. The range in thickness of the formation in Prowers County is nct known. A thickness of 380 feet was reported by McLaughlin (1954, p. 90) along Two Butte Creek in north-central Baca County; however, it seems to the present writers that the unit called Entrada at this point is actually a sandstone unit in the Dockum Group. The Dockum and Entrada in this area are extremely similar, and an erroneous designation of the sandstone as Entrada is understandable. The total thickness of the Entrada at this point probably is closer to 80 feet. Possibly the Entrada exceeds 100 feet in thickness in some parts of the county. An oil prospect in T. 24 S., R. 47 W., penetrated about 450 feet of sandstone of Triassic and Jurassic age; probably a part of this thick sandstone sequence is Entrada.

Water supply.—The Entrada Sandstone is not known to yield water to wells in Prowers County. In the areas underlain by thick sandstone beds of Triassic and Jurassic age, some water might be obtained. In most parts of the county, the Entrada lies at great depth below the productive Dakota Sandstone and Cheyenne Sandstone Member of the Purgatoire Formation. However, the water may be of good quality.

MIDDLE UNIT OF JURASSIC AGE

The name "middle unit of Jurassic age," as used in this report, refers to the sandstone, limestone, mudstone, conglomerate, and chert zones beneath the Morrison Formation and above the Entrada Sandstone.

This unit of the Jurassic has been located in surroundirg regions, and many names have been applied to it, such as the Wanakah and Sundance Formations, and, less commonly, the Curtis and Summervill Formations. The subsurface distribution of the unit is shown in figure 15. The unit is distinctively separated from the Morrison Formation by a zone composed of nodular red to orange beds of chalcedony. The nodular zone was noted by earlier geologists in the region (Lee, 1902, p. 44; Merriam, 1955, p. 32). The apparent thickness of the middle unit in Prowers County, as shown by the logs of oil prospects, ranges from less than 35 to as much as 150 feet. The true thickness of the unit is not readily discernible because the contact between the middle unit and the underlying Entrada Sandstone is not easily recognized.

The unit is not considered to be an aquifer in Prowers County.

MORRISON FORMATION

The name "Morrison Formation," as used in this report, refers to the varicolored marl, shale, and sandstone sequence beneath the Purgatoire Formation and above the middle unit of Jurassic ege.

The Morrison Formation in the vicinity of Two Buttes dome along Two Butte Creek has been described by Sanders (1934, p. 865).

Character.—The Morrison Formation in Prowers Courty is composed chiefly of marl, siltstone, mudstone, and shale containing sandstone, platy limestone, and conglomerate. In much of the county the shale beds are multicolored; green commonly predominates. In places, the sandstone is silicified and is extremely hard; in other places, lenses of sandstone are relatively soft. In the vicintity of Two Buttes, the upper part of the formation contains silicified logs as much as 30 feet long and 3 feet in diameter.

Distribution and thickness.—The Morrison Formation crops out north and east of Two Buttes (pl. 1), where it is resistant to erosion. In the subsurface, the Morrison Formation underlies all of Prowers County except the southeast corner, where Jurassic rocks are absent (fig. 1b). The thickness of the Morrison Formation ranges from less than 20 to about 240 feet, as indicated by logs of oil prospects. The contact between the Morrison Formation and the overlying Cheyenne Sandstone Member of the Purgatoire Formation usually is clearly indicated by differences in lithologic characteristics and color.

Water supply.—Twelve wells in the Two Buttes area obtain water from the the Morrison Formation. The well owners report that the quality of the water is good and that supplies are adequate for domestic and stock demands. The water in this area is derived chiefly from the soft sandy lenses of the unit. In other parts of the county, wells tapping overlying aquifers may have penetrated water-bearing beds in the Morrison, which may contribute to the well discharge. However, the Morrison Formation consists chiefly of fine-grained sediments that contain little or no ground water.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

PURGATOIRE FORMATION

The Purgatoire Formation in Prowers County rests on the Morrison Formation of Jurassic age, except in the southeastern part, where the Jurassic and Triassic are absent and the formation overlies the Permian. Except where the Purgatorie Formation crops out, the unit is overlain by the Dakota Sandstone. The Purgatoire includes the Chevenne Sandstone and the Kiowa Shale Members. For many years, the term "Dakota" was used to designate all the present Purgatoire Formation and the overlying Dakota Sandstone. The Cheyenne Sandstone Member is still spoken of by local residents as the "lower Dakota," and the Dakota Sandstone is spoken of as the "upper Dakota." Members of the Pugatoire Formation have been identified east and south of Prowers County (Latta, 1941, p. 70; McLaughlin, 1943, p. 32; 1954, p. 97). The two members of the Purgatorie have been traced from their type locality in Kiowa County, Kans., westward to the type locality of the Purgatoire Formation in Las Animas County, Colo., (McLaughlin, 1954, p. 97).

The Kiowa Shale and Cheyenne Sandstone Members of the Purgatoire Formation in Prowers County are equivalent to the Kiowa Shale and Cheyenne Sandstone of central and western Kansas.

CHEYENNE SANDSTONE MEMBER

The Cheyenne Sandstone Member is the lower member of the Purgatoire Formation and underlies the Kiowa Shale Member.

Character.—The Cheyenne Member consists chiefly of light-colored fine- to coarse-grained, loosely cemented, massive friable sandstone. Locally, the member contains gray shale lenses and well-cemented zones. The lighter color and the relatively soft character of the sandstone are the two basic characteristics distinguishing it from the Dakota Sandstone, which is usually better cemented and in some places is multicolored.

Distribution and thickness.—The Cheyenne Sandstone Member crops out in two areas in the vicinity of Two Buttes (pl. 1). It underlies the entire county except in those places where rocks of pre-Cheyenne age crop out.

The thickness of the Cheyenne Sandstone Member ranges from about 30 feet in the south-central part of the county to a maximum of

about 200 feet in the central part in T. 23 S., R. 45 W.

Water supply.—The Cheyenne Sandstone Member is a major aquifer in Prowers County, although it is not extensively developed. The material appears to be extremely permeable, although it contains a few impermeable lenses of shale. In most parts of the county, except in and near the outcrop areas, water in the Cheyenne Member is under artesian pressure. In some areas, the water is under sufficient pressure to flow at the land surface.

The Cheyenne Sandstone Member may be expected to produce useful quantities of water in all parts of the county, except possibly in and near the outcrops or where the member has been incised and is drained. In the area 18 miles south of Holly, successful large-capacity wells obtain water from the Ogallala Formation, Dakota Sandstone, and Cheyenne Member. The lithologic character at this locality indicates that the Cheyenne Member may be the principal source of water for these successful wells.

KIOWA SHALE MEMBER

Character.—The Kiowa Shale Member, the upper member of the Purgatoire Formation, is overlain by the Dakota Sandstone and underlain by the Cheyenne Sandstone Member. The Kiowa Member consists principally of dark-gray to black clayey shale containing sandy shale, siltstone, and, in the upper part, thin beds of sandstone. Locally, the shale is calcareous and contains gypsum.

Distribution and thickness.—The Kiowa Member crops out about 5 miles north of Two Buttes (pl. 1). Elsewhere in the county, the

Kiowa underlies the Dakota Sandstone.

The Kiowa Shale Member ranges in thickness from 30 to 140 feet, reaching the maximum of 140 feet in the central part of the county. Generally, the thickness is less than 100 feet.

Water supply.—The Kiowa Member does not yield water to wells in Prowers County, but it acts as an extensive confining layer over the underlying Cheyenne Sandstone Member. The Kiowa Shale Member prevents any appreciable movement of water between the Dakota Sandstone and the Cheyenne Sandstone Member.

DAKOTA SANDSTONE

The alternating beds of sandstone and shale constituting the Dakota Sandstone overlie the Purgatoire Formation and underlie the Gran⁷⁴³⁻⁰³³ O-65-5

eros Shale. The term "Dakota" is used by many local inhabitants to include not only the Dakota Sandstone but also the Cheyenne Sandstone Member of the Purgatoire Formation.

Character.—The Dakota Sandstone exhibits a wide variety of lithologic characteristics in Prowers County. In some places, it consists mainly of massive sandstone; in others, it is made up chiefly of very sandy shale and a few thin sandstone layers (fig. 16). The hardness of the sandstone differs greatly from place to place. In some places, iron has cemented the material, forming extremely hard rocks; in others, the iron has little effect other than coloration. The shale in the Dakota is multicolored at many places and can be mistaken for the multicolored shale of the Morrison Formation. In some areas, the Dakota is capped by hard ironstone.

Many of the sandstone beds in the Dakota are crossbedded and uniformly fine grained; however, the grain size may differ widely from bed to bed. The Dakota Sandstone is usually tan to brown, but may be white, light gray, or yellow, depending primarily upon the iron content.



Figure 16.—Outcrop of Dakota Sandstone along U.S. Highway 287, 22 miles south of Lamar, showing layers of massive sandstone and interbedded shale.

The massive beds of the Dakota Sandstone weather to form characteristic steep cliffs and ledges. Isolated sandstone blocks of resistant material are common in the outcrop areas (fig. 17).

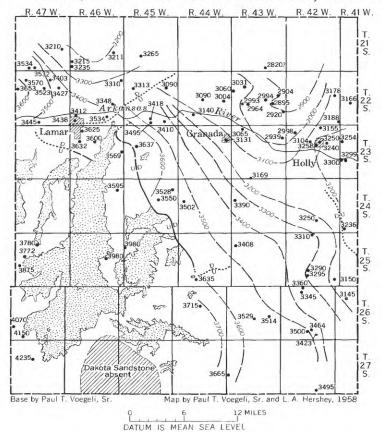
The shale interbedded with sand and siltstone in the Dakota is generally gray to black, but also may be of other colors. The beds of shale are discontinuous over short distances, even in those places where the thickness of the bed exceeds 2 feet. The interbedded shale is readily eroded. Where it is associated with the massive sandstone, steep talus-covered slopes are left; in areas where the massive sandstone is absent, the shale forms gentle soil-covered slopes.

Distribution and thickness.—The Dakota Sandstone is more extensive than any other consolidated formation in Prowers County. The formation crops out in most of the western half of the county south of the Arkansas River (pl. 1). In the northeastern part of the county, the Dakota Sandstone is as much as 800 feet below the surface (fig. 18).

The thickness of the Dakota Sandstone is difficult to determine because the upper part of the formation has been removed by erosion. The most complete section known is in T. 27 S., R. 47 W., but even here neither the base nor the top of the formation is exposed. The



FIGURE 17.—Blocks of resistant Dakota Sandstone along U.S. Highway 287, 23 miles south of Lamar.



EXPLANATION

Dakota Sandstone present at the land surface

Fault

Dashed where approximately located; dotted where concealed. U, upthrown side; D, downthrown side

Contour on surface of the Dakota Sandstone
Altitude, in feet, above mean sea level. Contour interval
100 feet
4235

Surface of Dakota Sandstone in well or test hole Number refers to altitude of Dakota Sandstone surface in well or test hole

FIGURE 18 .- Altitude of the surface of the Dakota Sandstone

total measured thickness is 120 feet. Where the Dakota Sandstone crops out, well data commonly indicate thicknesses less than 100 feet. Where the Dakota is overlain by younger formations, wells penetrating the full Dakota section show a range in thickness from 150 to 235 feet. A thickness of 175 to 200 feet is the most common. The Dakota probably is thickest about 18 miles south of Holly.

Age and correlation.—The Dakota Sandstone has long been considered a part of the Upper Cretaceous Series; however, studies by Cobban and Reeside (1951, p. 1892) and by Katich (1951, p. 2093) indicate the boundary between the Lower and Upper Cretaceous in western Colorado is above the Dakota Sandstone. McLaughlin (1954, p. 108) collected a fossil (*Trigoia emori* Conrad) from the Dakota Sandstone in northeastern Baca County that probably is of Early Cretaceous age. Fossils collected from the limestone sequence in the Graneros Shale overlying the Dakota have been shown to be of Late Cretaceous age; they indicate that the boundary between the Lower and Upper Cretaceous Series in southeastern Colorado is at the Dakota-Graneros contact.

Water supply.—The Dakota Sandstone is the most videspread aguifer in Prowers County. Although the formation does not yield large quantities of water to most wells, and in some areas is nonproductive, it is a dependable source of water for domestic, public, and stock supplies in many parts of the county. The Dakota Sandstone is the chief source of ground water of good quality in those parts of the county that are underlain by deeper aquifers. The formations between the Dakota and the Ogallala contain little water suitable for domestic and stock supplies. North of the Arkansas River, although the depth to the top of the formation is as much as 850 feet, the Dakota provides the only source of usable domestic water. In Baca County and other parts of southeastern Colorado, the Dakota Sandstone has been deeply dissected and drained. In Prowers County, it is drained only in a small area in the northeast corner of T. 27 S., R. 47 W., where the Dakota has not been fully dissected but probably has been drained to the exposed depth of the formation. In those parts of the county where the Dakota crops out and is thin, the underlying Cheyenne Sandstone Member probably would yield moderate to large quantities of water to wells.

The ability of the Dakota to yield water depends upon its permeability, which, locally, may be low. Drillers report that some wells penetrated thick sequences of shale and relatively impermeable sandstone and did not yield the amount of water normally available from the Dakota.

Depths of wells tapping the Dakota differ from place to place. Wells drilled in places where the Dakota crops out range from about 50 to 200 feet deep. In the parts of Prowers County where the Dakota is overlain by younger formations, water is reached at depth a ranging from 200 to 900 feet.

Water levels in wells tapping the Dakota Sandstone differ also from place to place (fig. 9). Water levels range from 22 feet above to 425 feet below the land surface, depending upon the altitude of the land surface in respect to that of the piezometric surface.

The quantity of water available to wells from the Dakota depends on the permeability of the rocks near the well. The yields of wells drilled in the Dakota range from a few gallons to several hundred gallons per minute.

UPPER CRETACEOUS SERIES GRANEROS SHALE

The Graneros Shale is underlain by the Dakota Sandstone and overlain by the Lincoln Limestone Member of the Greenhorn Limestone. Gilbert (1896b, p. 564) originally included strata of the Lincoln Limestone and Hartland Shale Members of the Greenhorn in the Graneros Shale.

Character.—The Graneros consists chiefly of gray to grayish-black shale. The shale is platy and noncalcareous in most outcrops. Locally, it is slightly calcareous. The formation contains thin beds of bentonite and a resistant limestone bed (Thatcher Limestone Member; fig. 19) that is 20 to 50 feet above the Dakota Sandstone.

The Graneros contains a few very thin layers of brown sandy clay. In many outcrops of the Graneros in Prowers County, stringers of gypsum in horizontal or vertical planes are included in the shale. These "plates" of gypsum are as much as 1 foot long and 1 foot wide, and range from ½ to ¾ inches in thickness. Gypsum, in varying amounts, may be found in all Graneros outcrops. The shale has little resistance to erosion and forms gentle soil-covered slopes, except where the formation has been freshly exposed by stream cutting or where it is protected by overlying ledges of the Lincoln Limestone Member of the Graneros Shale also provides a ledge that acts as a protective cover and prevents erosion of the lower parts of the formation (fig. 20).

The Graneros Shale contains many beds of bentonite, most of which range in thickness from less than 1 to as much as 3 inches. The principal bed of bentonite in the Graneros Shale is 4 to 8 feet below the basal limestone member of the Greenhorn Limestone. In most outcrops, the uppermost bentonite bed ranges in thickness from 8 to 12 inches, but beds as thick as 25 inches were observed in the south-

central part of T. 27 S., R. 47 W. The bentonite is light-gray to white on fresh and weathered surfaces, although it is stained locally by iron oxide. The beds are structureless and break with a pronounced conchoidal fracture.

The Thatcher Limestone Member of the Graneros Shale is the most distinctive unit within the formation. The limestone sequence occurs

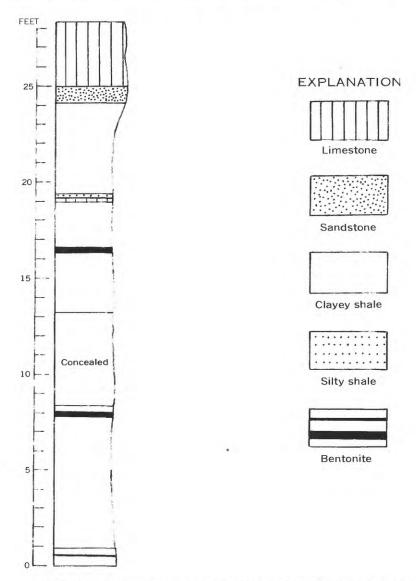


FIGURE 19.—Stratigraphic section of the middle and lower parts of the Graneros Shale in the NE1/4 sec. 18, T. 24 S., R. 44 W.

in Baca County and has been described by McLaughlin (1954, p. 112). The limestone unit in Baca and Prowers Counties is similar to that in Las Animas County described by Bass (1947). In Prowers County, the unit is from 2.5 to 5.5 feet thick and consists of yellowish-brown, very fine grained limestone. The unit is very platy, has irregular edges, and weathers to sharp angular chips. Parts of the sparsely fossiliferous limestone unit are petroliferous in some parts of Prowers County. The lithologic and physical characteristics of the Thatcher are similar to parts of the Lincoln Limestone Member of the Greenhorn Limestone and where only a small part of the Thatcher is exposed, the unit could be readily mistaken for the Lincoln. One of the prominent characteristics of the Thatcher Member is the large blocks that occur in relatively unweathered exposures (fig. 21). The large blocks eventually deteriorate into small rusty-brown chips. ledges formed by the Thatcher Limestone Member aid in the mapping of the Graneros in places where the formation has been weathered to wide gentle slopes.

Distribution and thickness.—The Graneros crops out chiefly in areas southwest and southeast of Lamar and also along Two Butte Creek in the extreme southwestern part of the county (pl. 1). It underlies younger formations throughout the county, except in the vicinity of Two Buttes which is underlain only by pre-Upper Cretaceous rocks.

The thickness of the Graneros is uniform throughout the county, ranging from about 85 to 100 feet. The measured thickness in sec. 26, T. 24 S., R. 45 W., is 99 feet. The Graneros has about the same

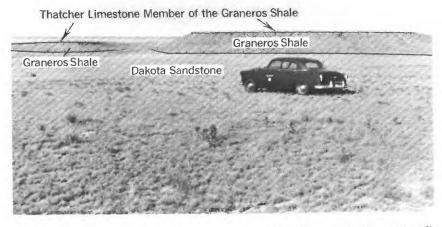


FIGURE 20.—Resistant Thatcher Limestone Member of the Graneros Shale capping soft Graneros Shale. Upper part of Dakota Sandstone is at the base of the slope. Outcrop is on the Hasser Ranch in the SE14 sec. 3, T. 27 S., R. 47 W.

thickness in the western part of Prowers County as it has in Las Animas County and other areas westward, but it thins in the eastern part. It is 86 feet thick in Baca County, Colo., (McLaughlin, 1954, p. 17); 61 feet thick in Hamilton County, Kans.; and 105 feet thick in the Model anticline in Las Animas County, Colo., (Bass, 1926, p. 59; 1947).

Age and correlation.—The Graneros Shale in Prowers County is equivalent to the Graneros in other parts of southeastern Colorado as well as in western Kansas. The limestone is equivalent to the Thatcher Limestone Member in Baca County (McLaughlin, 1954, p. 114).

Water Supply.—Although little or no water is available from the Graneros, the formation has an important role in the ground-water hydrology of the county; it confines the water in the Dakota Sandstone under artesian pressure.

GREENHORN LIMESTONE

The Greenhorn Limestone is overlain by the Fairport Chalky Shale Member of the Carlile Formation and is underlain by the Graneros



Figure 21.—Thatcher Limestone Member of the Graneros Shale in the center of sec. 18, T. 23 S., R. 45 W.

Shale. The Greenhorn consists of three members, which are, in ascending order, the Lincoln Limestone, the Hartland Shale, and the Bridge Creek Limestone. The Greenhorn Limestone crops out in many parts of the county except in the northern part; there it is overlain by younger formations (pl. 1). On the geologic map (pl. 1), the Greenhorn Limestone is divided into its three component members in areas where individual members were readily differentiated. Where the formation crops out in wide gentle soil-covered slopes, separation of the Greenhorn into its respective members was not feasible.

Character.—The Lincoln Limestone Member in Prowers County consists principally of silty and clayey shale containing beds of clayey limestone and bentonite. The hard fossiliferous petroliferous thinly bedded grayish-brown limestone layers near the top and the base of the member form distinctive benches in the outcrop areas. gravish-brown limestone layers are similar to the Thatcher Limestone Member of the Graneros Shale, and they may be readily mistaken for one another in the field. One difference is that the Lincoln Member is more fossiliferous than the Thatcher Member. Figure 22, sections A and C, show that beds of bentonite occur in the member, principally in the upper part. The Lincoln has a measured thickness of 37 feet in sec. 26, T. 34 S., R. 45 W. The member is about 25 feet thick in Baca County (McLaughlin, 1954, p. 115); eastward in Hamilton County, Kans., it is 35 feet thick (Bass, 1926, p. 59). The member thins westward and is reported by Bass (1947) to be 19 feet thick in the Model anticline in Las Animas County, Colo.

The Hartland Shale Member consists chiefly of yellowish-orange chalky shale separated by yellowish-orange chalky limestone layers ranging from ½ to ½ feet thick and a few layers of bentonite generally less than 1 inch thick. In a few places the limestone layers are hard and form resistant ledges; however, in most places the layers are soft and grade into chalky shale. The measured thickness of the Hartland in Prowers County is 38 feet in sec. 26, T. 24 S., R. 45 W. (fig. 22, section A). McLaughlin (1954, p. 116) reports the Hartland to be 30 feet thick in northwestern Baca County. Thicknesses of 23 feet in Hamilton County, Kans., and 29 feet in the Model anticline are reported by Bass (1926, p. 59; 1947).

The Bridge Creek Limestone Member of the Greenhorn Formation consists of alternating beds of limestone and shale and a few layers of bentonite (fig. 23). The beds of limestone are from 3 to 14 inches thick and are separated by 4 inches to 4 feet of shale and, where present, by bentonite layers 2 to 6 inches thick. The beds are mostly dense, are light to dark gray on fresh exposures, and weather to chalky white. In many places the limestone grades into the underlying or overlying

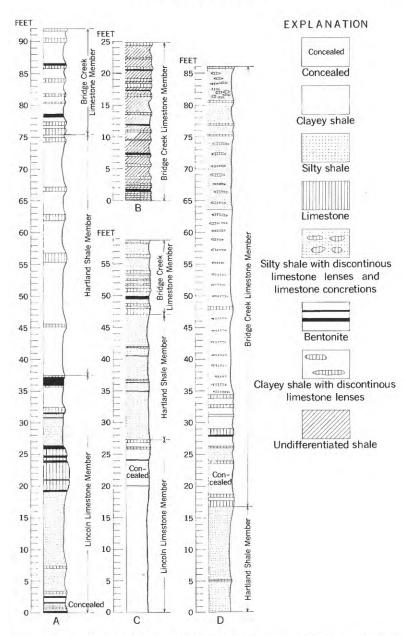


FIGURE 22.—Stratigraphic sections of part of the Greenhorn Limestone. Section A was measured in the SW¼ sec. 26, T. 24 S., R. 45 W.; section B was measured in the NW¼ sec. 14, T. 23 S., R. 43 W.; section C was measured in the NW¼ sec. 29, T. 27 S., R. 47 W.; Prowers County, Colo.; section D was measured in the NW¼ sec. 14, T. 28 S., R. 48 W., Baca County, Colo.

shale, but in some places the contact between it and the shale is clearly defined. Fossils are common in nearly all the limestone but are more abundant in the upper parts of the member. The limestone beds are much more resistant to erosion than the included shale beds; they form distinct benches, which are readily detected on aerial photographs and in the field.

The basal limestone and the shale, limestone, and bentonite layers near the base of the Bridge Creek are lithologically similar throughout Prowers County. The basal chalky light-gray limestone is from 10 to 14 inches thick and is overlain by silty shale, which ranges from 4 to 5 inches in thickness. The shale is overlain by chalky limestone which, because of its characteristic rounded top surface, has been called the "biscuit bed" limestone of the Bridge Creek by some geologists. The "biscuit bed" is overlain by a yellowish-orange bentonite from 4 to 6 inches thick. The stratigraphic relation and the thickness of these basal units remain fairly constant throughout the county.

In the upper parts of the Bridge Creek Limestone Member in Prowers County, continuous limestone layers are fewer and discontinuous limestone lenses are more prevalent. The shale in the upper part of the member includes many thin bands of limestone, which commonly

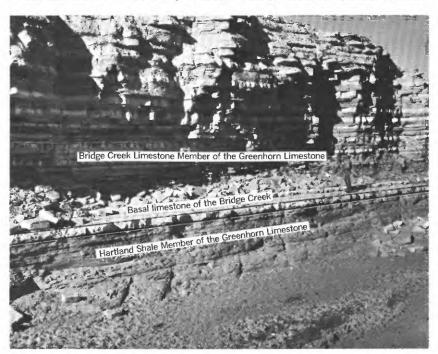


FIGURE 23.—Outcrop of Hartland Shale and Bridge Creek Limestone Members of the Greenhorn Limestone in the SE¼ sec. 30, T. 26 S., R. 43 W.

are petroliferous. Many concretions, abundantly fossiliferous, occur in the upper part of the member. The contact between the Bridge Creek Limetsone Member and the Fairport Chalky Shale Member of the Carlile Shale is not readily recognizable because the upper beds of the Bridge Creek are lithologically similar to the shale of the Fairport. However, in many places the contact may be determined by characteristics of the uppermost limestone unit in the Bridge Creek. The uppermost bed is a yellowish-gray limestone, having thin rusty bands near the center. The limestone unit weathers into blocks similar to the "fence-post limestone" found in northwestern Kangas. The bed in Prowers County probably is equivalent to the Kansas unit. Many of the thin limestone lenses included in the shale associated with the "fence-post limestone" are extremely fossiliferous and emit a strong petroliferous odor when freshly broken.

The measured thickness of the Bridge Creek Limestone Member is 73 feet in the SW1/4 sec. 18, T. 27 S., R. 47 W., and is 69 feet in northwestern Baca County.

Distribution and thickness.—The Greenhorn Limestone crops out chiefly in the central part of Prowers County. It again crops out south of the Arkansas River in the western part of the county along the Bent County line and also along Two Butte Creek in the southeastern part (pl. 1). The formation underlies younger formations except in the southeastern part of the county, where the Greenhorn has not been penetrated by wells drilled through the Ogallala Formation into the underlying bedrock.

The Greenhorn is about 130 feet thick in Prowers County. In Baca County it is about 115 feet thick (McLaughlin, 1954, p. 119). The formation thickens eastward and is 132 feet thick in Hamilton County, Kans. (Bass, 1926, p. 59); it thins westward to 83 feet in the Model anticline in Las Animas County (Bass, 1947).

Age and correlation.—The Greenhorn in Prowers County is of Late Cretaceous age and is equivalent to the Greenhorn of western Kansas and other parts of southeastern Colorado. The Bridge Creek Limestone Member is equivalent to the entire section of the Greenhorn limestone, as defined by Gilbert (1896b, p. 564) at the type locality in Pueblo County, Colo. Rocks now assigned to the Lincoln Limestone and Hartland Shale Members were originally included in the Graneros Shale by Gilbert; however, these members are now considered to be a part of the Greenhorn in southeastern Colorado.

Water supply.—The Greenhorn, principally the Bridge Creek Limestone Member, yields small quantities of water to a few stock wells in Prowers County. The chemical quality is likely to be poor and the water unsuitable for domestic supply.

In areas where the Greenhorn crops out, the underlying Dakota Sandstone should be a much better source of water. The maximum depth to the top of the Dakota Sandstone in areas overlain by the Greenhorn is about 230 feet; the minimum depth ranges from about 85 to 100 feet.

CARLILE SHALE

The Carlile Shale was named by G. K. Gilbert (1896b, p. 565) from exposures of gray clayey shale along Carlile Creek 21 miles south of Pueblo, Colo. The Carlile is overlain by the Fort Hays Limestone Member of the Niobrara Formation and is underlain by the Bridge Creek Limestone Member of the Greenhorn. The Carlile consists of three members, which are, in ascending order, the Fairport Chalky Shale, the Blue Hill Shale, and the Codell Sandstone.

Character.—The Fairport Chalky Shale Member consists chiefly of white chalky shale, black fissile shale, and layers of thin limestone. The lower part of the Fairport consists of yellowish-white chalky shale and thin layers of limestone. The limestone zone of the lower part of the Fairport contains 11 layers of thin chalky limestone, which may be as much as 1 foot thick in places. This 11-layer sequence occurs in Hamilton County, Kans., (Bass, 1926, p. 65), and was observed in Prowers County by the writers along Chevenne Creek in the SW1/4 sec. 32, T. 22 S., R. 41 W. The layers seem to be similar to the underlying Bridge Creek Limestone Member but generally are softer and fracture into blocks. Owing to the similarity of the Fairport and the Bridge Creek, the contact between the two members can be ascertained only by an examination of the fossils in the two units. The lower part of the Fairport grades into noncalcareous dark-gray to black sandy fissile shale. Where the shale is fractured, gypsum has been deposited by circulating ground water. In some places the gypsum is porous. Thin beds of bentonite, more numerous in the lower part, occur throughout the Fairport. Thin lenses of gray to brown limestone occur throughout the shale; commonly the limestone is made up entirely of fossil debris. Fossil impressions of coiled ammonites, remains of the oyster, Ostrea, and the clam, Inoceramus, are common throughout the Fairport.

The Blue Hill Shale Member is a highly fissile noncalcareous platy blue-black shale that contains abundant selenite. It is readily distinguished from the chalky shale of the Fairport. Large septariam concretions, as much as 4 feet in diameter, occur in the upper 20 feet of the Blue Hill. The concretions are composed of dense bluish-gray limestone, which weathers to a buff color. In the center of concretions found in the NE½ sec. 4, T. 22 S., R. 43 W., are large calcite crystals as long as 1½ inches that display cone-in-cone structure and have a

dull pinkish weathered coating. Some calcite crystals have been altered to a light-golden fibrous aragonite, which has a woody appearance. Some of the concretions are encased in a thin envelope of interlocking gypsum crystals, whereas others have a thicker shell of conein-cone calcite. Similar concretionary zones, in approximately the same stratigraphic position, were reported in western Kansas and in Baca and Bent Counties, Colo., (Bass, 1926, p. 63; McLaughlin, 1954, p. 121; Dane, Pierce, and Reeside, Jr., 1937, p. 216). The contacts of the Blue Hill with the overlying and underlying units are generally sharp and conformable.

The Codell Sandstone Member marks the upper limit of the Carlile Shale. It is chiefly sandy shale capped by a calcareous brown sandstone of variable thickness. The proportion of sand to lime in the capping unit differs across the county. In places the urit is a thin brown sandy crystalline fossiliferous limestone which emits a strong petroliferous odor when freshly exposed. In some areas, the limestone is a massive layer 5 feet thick; in others, it is an irregularly bedded unit, the individual layers thin enough to be measured in inches. The capping unit not only differs in thickness but also in the character of its bedding. In some areas, the limestone unit is represented by a thin slab of dark-colored crystalline limestone enclosed in the basal chalky limestone of the overlying Fort Hays Member of the Niobrara Formation. The sandstone underlying the caprock is very shaly and is represented generally by lenticular thin sandstone and siltstone layers included in a massive silty shale bed. Except for the capping unit, the Codell is noncalcareous.

Distribution and thickness.—The Carlile Shale under ies most of the area north of the Arkansas River and crops out in a 70 square-mile area south of the Arkansas River and northwest of Plumb Creek between Granada and Carlton. The Carlile also crops out on a structural high southeast of Lamar in parts of secs. 12–13, T. 24 S., R. 46 W.

The Carlile is about 200 feet thick in Prowers County but thins to the south and southwest. It is 85 feet thick in Baca County and 160 feet thick in the Model anticline in north-central Las Animas County (McLaughlin, 1954, p. 122; Bass, 1947). It thickens to 250 feet in Hamilton County, Kans., and to about 300 feet in Ellis County, Kans., (Bass, 1926, p. 15).

Age and correlation.—The Carlile and its three members in Prowers County are of Late Cretaceous age and are equivalent to the Carlile of western Kansas and of other parts of southeastern Colorado. The subdivisions of the Carlile recognized in western Kansas (Bass, 1926, p. 59) were also recognized as Upper Cretaceous in the Arkansas Valley in eastern Colorado (Dane, Pierce, and Reeside, Jr., 1937, p. 215).

The limestone and shaly sandstone of the Codell grades eastward into sandstone and can be traced westward to the foothills of the Front Range in Las Animas, Huerfano, and Pueblo Counties, Colo., (McLaughlin, 1954, p. 122).

Water supply.—The Carlile Shale yields small quantities of water of poor quality to a few wells in Prowers County. The capping limestone of the Codell Sandstone Member and the basal limestone of the Fairport Chalky Shale Member yield small quantities of water from saturated fractured zones. Black to dark-gray water, containing hydrogen sulphide and emitting a strong odor, is produced from a few wells tapping the Carlile Shale northwest of Lamar. Seeps are common at the contact zone of the Blue Hill and the Fairport. Small stock supplies have been obtained by the excavation of collecting basins where this zone is exposed east of Chevenne Creek in western Kansas. Where the Carlile crops out (pl. 1), the Dakota Sandstone is the shallowest aquifier capable of yielding dependable domestic and stock water to wells. The top of the Dakota Sandstone lies about 230 feet below the contact of the Carlile with the underlying Greenhorn Limestone and 440 feet below the contact of the Carlile and the overlying Niobrara Formation. Additional quantities of water may be obtained at greater depth from the Cheyenne Sandstone Member of the Purgatoire Formation.

NIOBRARA FORMATION

The Niobrara Formation in Prowers County lies above the Carlile Shale and is the youngest Late Cretaceous formation in the county. The Niobrara Formation was named by Meek and Hayden (1862, p. 419) from exposures of calcareous marl and chalky limestone near the mouth of the Niobrara River in northeastern Nebraska. Williston (1893, p. 108) recognized a lower "stratified" limestone unit and called it the Fort Hays beds. He traced the chalk and limestone across Kansas from the vicinity of Mankato to an area north and west of Coolidge and to the west. F. W. Cragin (1896, p. 51) designated the upper series of chalky and marly limestone and shale as the Smoky Hill and described it as overlying the Osborne (Fort Hays of current usage) Limestone.

FORT HAYS LIMESTONE MEMBER

The Fort Hays Limestone Member was originally included in the Fort Hays Division or Group of Mudge (1876) and was named by him for exposures at old Fort Hays in western Kansas. The upper part of his Fort Hays is classified now as the lower member of the Niobrara Formation. The limestone has been traced from western

Kansas into Bent County, Colo., where it forms prominent escarpments.

Character.—The Fort Hays Limestone Member consists of a series of massive to thin limestone beds that alternate with thin beds of medium to dark-gray, commonly fissile chalky shale or marl (figs. 24, 25).

The shale beds are highly susceptible to weathering but generally are protected by overlying benchlike limestone beds. Black dendrites (probably manganese dioxide) are common along the joint or bedding planes of the limestone. Conjugate joint systems, well developed in the limestone, provide permeable zones in the formation. Many of the joints are filled with intergrowths of calcium carbonate, which were precipitated from circulating ground water.

Fossils are abundant in the Fort Hays Limestone Member. The large clam, *Inoceramus*, is the most common macrofossil of the Fort Hays. The fossils occur as large casts or molds and also are represented by small clusters of shell fragments made up of calcite prisms. Fossil casts of *Inoceramus deformis* Meek as much as 7 inches long and 5 inches wide were found along the east bank of Wolf Creek west of the town of Granada. The genus is not found above the Fort Hays and, therefore, serves as an index to the lower member of the Niobrara

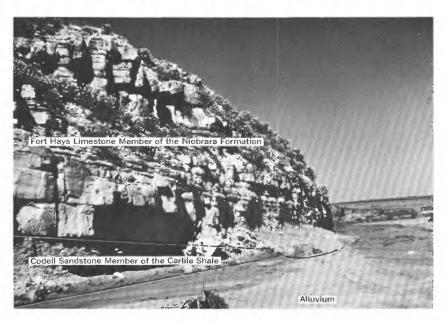


Figure 24.—Fort Hays Limestone Member of the Niobrara Formation on the west bank of Wild Horse Creek in the SE¼ sec. 21, T. 22 S., R. 42 W.

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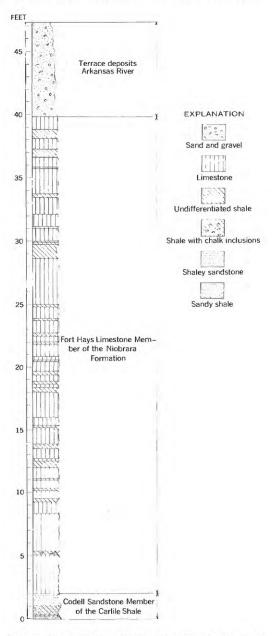


FIGURE 25.—Stratigraphic section including the Fort Hays Limestone Member of the Niobrara Formation measured on the west bank of Wild Horse Creek in the SE14 sec. 21, T. 22 S., R. 42 W.

Formation in Prowers County (Dane, Pierce, and Reeside, Jr., 1937, p. 221).

The basal 6 feet of the Fort Hays is characterized by two massive beds of limestone 3 feet thick, separated by a thin shale parting (fig. 26). The limestone contains well-defined intersecting joints. Irregular or capsule-shaped inclusions in the thick limestone are numerous and are composed of iron sulphide (pyrite or marcasite.) Fossils are not abundant in either of the limestone units, but a few sharks teeth, Ostrea and Inoceramus deformis Meek, are distributed near the base of the member. Outcrops of the basal unit are limited to the area north of Holly, Colo., and along Spring Creek north of Coolidge, The contact of the Fort Hays with the overlying Smoky Hill Marl Member appears to be gradational in the upper reaches of Cheyenne Creek in Hamilton County, Kans.; the contact was not recognized in Prowers County. Collapse structures, resulting from solution activity, occur in the member and may serve as collecting basins for the unconsolidated material under the terrace deposits north of the Arkansas River. Local faulting shown in figure 27 is generally associated with the collapse structures.

Distribution and thickness.—The Fort Hays Limestone Member is poorly exposed in Prowers County; it crops out mainly north of the Arkansas River in a band which swings gently southeastward to

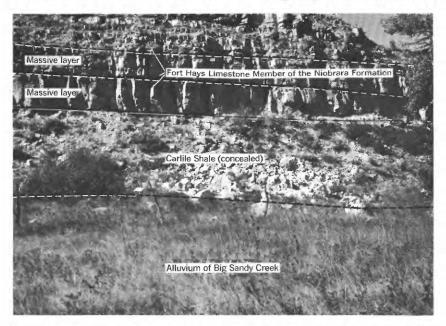


FIGURE 26.—Contact of the basal beds of the Fort Hays Limestone Member of the Niobrara Formation with the Codell Sandstone Member of the Carlile Shale on the west bank of Big Sandy Creek in the SE14 sec. 32, T. 21 S., R. 45 W.

Granada and rather sharply northeastward to the Kansas line. It crops out also in a small area about 14 miles south of Holly. The Fort Hays is mantled to the north by Tertiary and Quaternary deposits. The entire thickness of the Fort Hays in Prowers County could not be measured because of the mantle of Tertiary and Quaternary deposits, but the member seems to be about 60 feet thick in the subsurface, as shown in logs of oil prospects. This figure is similar to that reported by Bass (1926, p. 57) for Hamilton County, Kans.

Water supply.—The Fort Hays is capable of yielding moderate quantities of water to wells where solution channels or joint systems interconnect. Irrigation wells in the member reportedly yield 250 to 300 gpm.

Limestone beds of the Fort Hays were drained for about half a mile at the north end of the Pleasant Valley Drainage Ditch; the drain flow was measured at 120 gpm by the Soil Conservation Service. Irrigation ditches that traverse areas of outcrop undoubtedly contribute much of the water pumped from wells tapping the Fort Hays.

Springs are common in the Fort Hays and occasionally are used for supplemental water supplies. Several springs have been observed in the NW½sec. 31, T. 22 S., R. 44 W., where the aggregate yield is about 10 gpm.

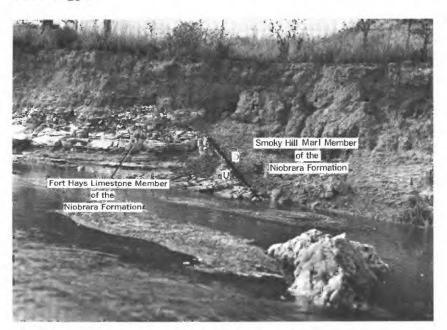


FIGURE 27.—Fault caused by the collapse of the Fort Hays Limestone Member of the Niobrara Formation exposed along Buffalo Creek in the SE¼ sec. 19, T. 22 S., R. 43 W.

SMOKY HILL MARL MEMBER

The Smoky Hill Marl Member is the uppermost member of the Niobrara Formation. It is overlain by the Ogallala Formation in the northeastern part of the county and by Quaternary deposits in the rest of the area north of the Arkansas River.

Character.—The unweathered Smoky Hill Marl Member is a medium- to dark-gray chalky shale alternating with marl beds, both of which contain abundant microfossils, fish scales, and sharks teeth. Nearly pure chalk beds occur locally near the base of the member. In places, the chalk beds are separated by thin beds of limestone. Abrupt lateral gradation from impure chalk and chalky shale into a rather dense marl occurs near the Kansas State line. This lateral gradation seems to be common in the lower part of the Smoky Hill Marl Member and may exist throughout the member. The color of drill cuttings from the Smoky Hill Marl Member differs greatly from that of weathered exposures. The weathered exposures are chiefly pale to yellowish orange—in marked contrast to the whiteness of the underlying Fort Hays Member. Elias (1931, p. 38) reported:

"* * * The gray color of the unweathered chalk is undoubtedly due to the fine particles of iron sulphide (pyrite or marcesite), which are more or less uniformly distributed through the rock and most probably represent the residue of the decayed organic matter." The shades of orange and red in stringers and laminae in the weathered Smoky Hill are probably due to the particular oxide or hydrated oxide that was formed during weathering. Spheroidal hematitic concretions averaging about 3 inches in diameter, derived from a highly weathered chalky shale, were observed in the NW1/4sec. 14, T. 22 S., R. 43 W., Hamilton County, Kans.

Parallel jointing in the Smoky Hill Marl Member is vertical to near vertical. The joint planes commonly are filled with gypsum in the form of selenite and satinspar, or calcite. The gypsum or calcite occurs as a network of welded crystals standing in relief on the weathered shale surface. In places, percolating ground water has dissolved the minerals in the joints; better avenues for ground-water movement are thus provided. A series of springs along the east bank of Buffalo Creek in sec. 18, T. 22 S., R. 43 W., issue from these openings.

Solution in the Smoky Hill Marl Member and underlying Fort Hays has caused collapse features and local faulting. Large exposures of the Smoky Hill Marl Member that dip more than 2° indicate such solution.

Distribution and thickness.—The Smoky Hill Marl Member crops out in and along Buffalo Creek 1 mile east of Bristol, and in small

scattered areas in the northern part of the county where the overlying unconsolidated material has been removed by erosion. The Smoky Hill Marl Member does not crop out south of the Arkansas River. Because it is easily eroded, the Smoky Hill Marl Member forms gentle slopes toward the Arkansas Valley. The Smoky Hill Marl Member underlying the surficial materials in the extreme north-central and northeastern parts of the county has a badland-type topography (pl. 6).

The thickness of the Smoky Hill Marl Member in Prowers County is not definitely known, but logs of oil prospects suggest that it probably does not exceed 150 feet.

Water supply.—The Smoky Hill Marl Member does not yield water to wells in Prowers County. Water passes through some of the open joints and enters the underlying Fort Hays Limestone Member.

The small amount of water in the Smoky Hill Marl Member is hard and is generally of poor chemical quality. The sulphate content is generally high owing to the iron sulphide in the formation.

TERTIARY SYSTEM

MIOCENE(?) AND PLIOCENE(?) SERIES

INTRUSIVE ROCKS

The intrusion of older sedimentary rocks by igneous rocks formed the laccolithic mass of Two Buttes in south-central Prowers County. Many dikes and a few sills associated with the intrusion crop out in Prowers and Baca Counties. The igneous activity was greatest in Prowers County in the vicinity of Two Buttes dome. About 50 dikes associated with the Two Buttes intrusion were reported by Gilbert (1896a, p. 819). Some of the dikes are more resistant to erosion than the surrounding sedimentary rocks and locally form small linear ridges standing 10 or 15 feet above the local land surface. The laccolithic mass at Two Buttes is primarily a porphyritic rock with phenocrysts of large plates of biotite and elongate green crystals of hornblende in a dense gray groundmass. The material is highly weathered, and fresh specimens are not readily found. The igneous rocks composing the dikes range from acidic to basic but are largely intermediate.

The elevated outcrop of the Morrison Formation and its vicinity, 4.5 miles north-northwest of the Two Buttes dome, has been subjected to some igneous activity. The "uplifted" appearance of the outcrop area suggests significant activity.

Two of three small areas on the Hassar Ranch in sec. 15, T. 27 S., R. 47 W., about 8 miles northwest of Two Buttes, also show the effects of having been associated with igneous activity, and a prominent dike crops out in the third. The dike, consisting of material similar to

that at Two Buttes, has intruded the Graneros Shale and possibly the Lincoln Limestone Member of the Greenhorn Limestone; the shale and its included bentonite have been altered by contact metamorphism a few feet from the dike. The dike—18 feet high, 20 feet long, and 10 to 12 feet wide—was exposed about 25 years ago (fig. 28).

The age of igneous activity in Prowers County appears to range from Miocene (?) to post-Pliocene time. In the SE½sec. 15, T. 27 S., R. 47 W., the thin mantle of sand and gravel overlying the Graneros Shale has been subjected to igneous activity. The fine sand and gravel, which includes shale fragments, could have been derived from the Ogallala Formation or sediments of later age that would date the age of the igneous activity in this area as Pliocene or post-Pliocene.

The youngest sedimentary formation transected by the igneous rocks in Prowers County is the Graneros Shale and possibly the Lincoln Limestone Member of the Greenhorn Formation. Rocks of Lincoln age have been transected in Baca County (McLaughlin, 1954, p. 125). Much of the area of igneous activity in Prowers County is overlain by the Ogallala Formation. Igneous material derived from the erosion of older intrusive rocks is included in parts of the Ogallala Formation. The igneous activity in southern Prowers County probably

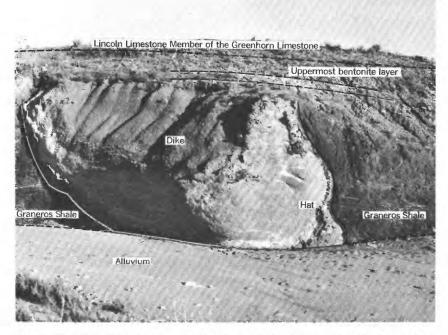


FIGURE 28.—Dike of Tertiary age that has intruded the Graneros Shale in the SW1/4 sec. 15, T. 27 S., R. 47 W.

commenced in Tertiary time. The algal limestone beds, which mark the top of the Ogallala Formation, dip steeply away from the flanks of Two Buttes. The dip of the limestone beds resulted from uplift in post-Ogallala time.

Intrusive rocks in Prowers County are not aquifers because of their

small extent and relative impermeability.

PLIOCENE SERIES OGALLALA FORMATION

The Ogallala Formation was named by Darton in 1898 from a locality in southwestern Nebraska. Hay (1895, p. 569) described these deposits in northwestern Kansas at an earlier date and recognized two divisions: the upper division, "Tertiary marl," and the lower division, "Tertiary grit." In eastern Colorado, beds of Tertiary age regarded as partly equivalent to the Ogallala were designated as upland gravels by Gilbert (1896b). These deposits were given the name "Nussbaum formation" in a detailed study of the Pueblo quadrangle (Gilbert, 1897, p. 4) and were regarded as Pliocene (?) in age. In this report, the formation of Pliocene age is called the Ogallala Formation.

The sediments of the Ogallala were transported by shifting streams having their origin in the Rocky Mountains. This type of deposition accounts for the general heterogeneity of the formation. Smith (1940, p. 85–86) in his discussion of the origin of the formation states:

The coarser beds of sand, gravel, and grit represent channel deposits, and in some places the channel form is evident * * *. The finer materials are best interpreted as representing floodwater deposits formed by the overflow of shallow channels, perhaps approaching the character of sheet-floods locally. * * * The deposition of the Ogallala formation began with the change from stream degradation to aggradation * * *. During the early stages of deposition, there was a topography of moderate relief. The main valleys were occupied by through-going streams from the Rocky Mountains, and the valley bottoms were mantled by normal floodplain deposits. * * * Deposition probably began with the filling of stream channels, leading to more frequent overflow and thus to the upbuilding of the floodplains. This soon led to shifting of the channels themselves, and probably to the development of anastomosing patterns. As filling progressed, the valley flat overlapped farther and farther on the slopes of the boardering hills, and the zone of deposition encroached farther and farther east and west. Relief was lowered, the valley plains grew broader, and finally the divides were overtopped, and there followed overlapping and coalescing of the depositional zones of individual streams. As depositional areas grew broader the rate of upbuilding must have declined, allowing greater time for the work of soil processes on the successive accretions of sediment. bedrock divides were buried deeper and deeper, and one vast, continuous alluvial plain came to extend from the slopes of the Rockies, perhaps as far as the Flint Hills in Kansas. * * * Eastward and westward the margins of the alluvial mantle thinned out against older rocks, and at the south the Sierra Grande highland probably rose gradually above the depositional surface. Over a great area, only one monadnock rose sharply above the alluvial plain—"Two

Buttes," in southeastern Colorado, held up by an igneous intrusion and surrounding altered sediments * * *.

In Prowers County the Ogallala Formation includes sediments younger than the consolidated rocks and older than the depoists of Pleistocene and Recent ages. The Ogallala Formation was mapped, for convenience, to include local deposits of the Meade (?) Group, which are Pleistocene in age (pl. 1).

Character.—The Ogallala Formation is poorly exposed in Prowers County because of its deeply weathered surface and extensive soil cover, and its character is revealed only by drill cuttings and in a few exposures along drainages (fig. 29). The Ogallala consists predominantly of gravel, sand, clay, silt, and caliche. These sediments generally are heterogeneous mixtures loosely cemented by calcium carbonate; the sand and gravel is cemented into hard mortar beds. A few thin limestone layers are present in the upper part of the formation. Most of the sand and gravel is poorly sorted, but some is well sorted locally, both vertically and laterally, within a short distance of the poorly sorted material. The sand and gravel beds are commonly crossbedded, and grade vertically and laterally into finer grained materials. Thin layers of very compact clay commonly are interbedded with sand and gravel, the clay layers becoming gritty in the lower part of the formation. Some of the coarsest material penetrated in the

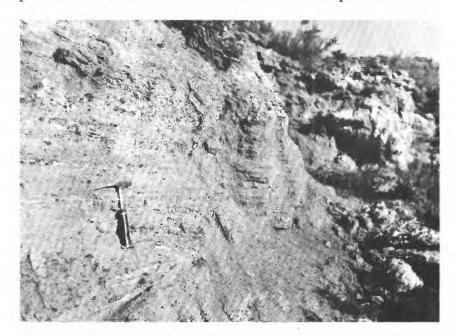


FIGURE 29.—Typical section of semiconsolidated sediments of the Ogallala Formation along the east bank of East Horse Creek in the SW1/4 sec. 23, T. 21 S., R. 42 W.

Ogallala was in test hole 26–42–24aaa, where boulders and cobbles were found associated with the clay. Most of the gravel layers under the water table in the southeastern part of the county are associated with clay or contain an abundance of finer grained sediments. Relatively clean gravel and sand zones were found above the water table in many of the test holes.

The beds of sand and gravel in the Ogallala are commonly cemented with calcium carbonate and less commonly with white opaline. The degree of cementation differs greatly, and a section of any mortar bed commonly contains friable zones. The mortar beds generally consist of coarse sand and gravel composed of grains of quartz and feldspar and, locally, may include large fragments of Mesozoic bedrock. Mortar beds weather rather rapidly and exhibit a highly irregular knobby surface, as shown in figure 30. Other mortar beds are firm and resistant, as shown in figure 31.

The silt in the Ogallala is mostly tan to buff but may be various shades of red. It is found usually in an admixture of sand or clay. Although silt is prevalent in the upper part of the Ogallala, it may also be found in other parts of the formation. Silt-sized particles are abundant in the Ogallala of southeastern Prowers County.



FIGURE 30.—Weathered mortar beds of the Ogallala Formation exposed in small tributary to East Horse Creek in the SW1/4 sec. 23, T. 21 S., R. 42 W.

The clay of the Ogallala ranges from shades of brown to green or gray. The clay generally is silty or sandy, but zones of nearly pure clay were penetrated in many test holes. The clay, when devoid of larger size particles, generally is compact and plastic, and generally is interbedded with layers of sand or gravel. Thick sections of gritty clay were penetrated in test holes in the extreme southeast corner of the county. A zone of differing thicknesses of brightly colored gritty bentonitic clay was penetrated in several test holes in the extreme southeast part of Prowers County. This zone may be equivalent to the Woodhouse Clay in Wallace County, Kans., described by Elias (1931, p. 155). The Woodhouse Clay of Elias underlies the mortar beds and rests on bedrock.

Caliche is common throughout the formation in admixtures of clay, silt, and sand. It resists erosion and, therefore, is observed commonly as thin ledges standing in relief with respect to the underlying material.

Most of the caliche penetrated in test holes and seen in exposures consisted of sand grains in a matrix of white to pinkish white granular calcium carbonate. Locally, the sand may be the predominant constituent, and the color may differ because of staining oxides leached from the associated gravel and clay deposits.



Figure 31.—Firmly cemented and resistant mortar beds of the Ogallala Formation in the SW1/4 sec. 7, T. 27 S., R. 46 W.

The hardest and most persistent unit of the Ogallala Formation is the capping limestone, which has been recognized in scattered areas throughout the Central High Plains. The presence of fossil algae Chlorellopsis bradleyi Elias in this limestone make it readily recognizable. The Limestone may grade laterally into a pseudopisolitic limestone that exhibits no evidence of algal structure. The algal limestone is pale yellowish red to light brown on freshly fractured surfaces; it weathers to a darker reddish brown coated with white calcium carbonate. Relief of the algal structures is accentuated by weathering; in many places individual concentric rings stand out in relief. Coarse sand grains also are present in the limestone but are generally scattered through the unit. Many large fragments of feldspar are present locally. The limestone crops out in several places. The principal outcrops are in the SW½sec. 36, T. 27 S., R. 45 W., and in the SW½sec. 23, T. 21 S., R. 42 W.

Although not observed in exposures, the Ogallala contains thin layers of opaline chalcedony in southeastern Prowers County. Thin hard streaks were encountered in drilling, and abundant chalcedony grains were observed in test-hole cuttings from there. No such streaks were observed in the small exposures in the northeastern part of the county. Similar layers were observed by McLaughlin on the northeast side of Carrizo Mesa and in the E½sec. 10, T. 33 S., R. 50 W., in southwestern Baca County (McLaughlin, 1954, p. 129).

No identifiable ash deposits were observed in Prowers County, but test-hole cuttings contained reworked and altered ashlike material in abundance.

Distribution and thickness.—The Ogallala is one of the most areally extensive formations in Prowers County (pl. 1). It underlies about half the area south of the Arkansas River and all the northeastern part of the county, where it is covered by a thick mantle of soil.

The thickness of the Ogallala in Prowers County ranges from 0 to about 440 feet. It is thickest in the southeastern part of the county and thins toward the west, where large areas of bedrock are exposed. Local thickening and thinning is partly the result of erosion on both the post- and pre-Pliocene surfaces. The Ogallala is very thin in the vicinity of Two Buttes dome, where the algal limestone rests directly on rocks of Permain age.

Age and correlation.—The Ogallala Formation, as herein described, includes those beds below the capping algal limestone and above the shale, sandstone, siltstone, and limestone of Cretaceous and pre-Cretaceous age. The Ogallala Formation of Colorado is equivalent to part of the Ogallala of western Kansas, western Nebraska, eastern Wyoming, and the High Plains areas of Oklahoma and Texas. The Ogallala of Prowers County is largely equivalent in age to that of

the type locality at Ogallala, Nebr., which is of Pliocene age; however, some of the basal beds in the county mapped with it may be older and, therefore, not formally part of the Ogallala.

The correlation of electric logs of test holes in the southeastern part of the county was poor. Correlation of individual beds is not feasible over large areas, but some of the beds may be correlated over short distances.

Water supply.—The Ogallala Formation is one of the principal aquifers in Prowers County. It yields adequate supplies of domestic and stock water to wells throughout a large part of the county. In 1958, the maximum yield from the Ogallala Formation was reported to be 800 gpm from well 27–41–19ccc. Wells tapping the Ogallala Formation in southeastern Prowers County probably will not yield more than 1,000 gpm. Wells completed in the cleaner gravel and sand of the Ogallala in the extreme northeastern part of the county yield as much as 2,000 gpm.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

MEADE(?) GROUP

Thin deposits of clay, silt, sand, and gravel of Pleistocene age overlie the Ogallala Formation and, in some places, rest unconformably on the bedrock formations of Prowers County. These deposits are probably equivalent to the Meade (?) Group of lower Pleistocene age in southwestern Kansas. No fossils were collected from these beds, and tentative correlation with the Meade (?) Group is based on their position above the capping algal limestone of the Ogallela; no age determination by fossils was attempted. An ash bed was observed in these deposits in several outcrops. Many of the ash deposits apparently have been reworked and contain silt, sand, and clay. The ash bed may be equivalent to the Pearlette Ash Member of the Sappa Formation near the top of the Meade (?) Group in Kensas (Frye and Leonard, 1952, p. 24).

Beds of indurated well-sorted medium sand that exhibit well-developed crossbedding occur locally. They generally are in channel fill composed of poorly sorted sand and gravel and scattered caliche nodules. Silt and silty clay, common throughout the Pleistocene section, include beds of nearly pure bentonite. Bentonitic clay was observed along Two Butte Creek. Where Pleistocene deposits overlie bedrock, they contain a large amount of material, chiefly pebbles and cobbles, derived from the underlying bedrock.

The Meade(?) Group crops out along most of the creeks in the southwestern part of the county, notably along Two Butte Creek in

sec. 34, T. 27 S., R. 45 W.; North Butte Creek in sec. 35, T. 26 S., R. 44 W.; and Wolf Creek in secs. 22 and 27, T. 24 S., R. 45 W. The sediments are commonly reddish brown and contain some chocolatebrown clay.

The thickness of the Meade (?) Group is not known in Prowers County, but it probably does not exceed 55 feet, as suggested by the A lack of exposures prohibit exact surface measurement test drilling. of the full section.

The Pleistocene deposits generally lie above the water table in southeastern Prowers County and, therefore, yield no water to wells. Where the deposits overlie bedrock, they often discharge small quantities of water from springs and seeps along their contact with the Because of the similarity and close relation of the Meade (?) and the Ogallala, the two units were mapped as one.

UNDIFFERENTIATED TERTIARY AND QUATERNARY DEPOSITS

Reworked sediments derived from the Upper Cretaceous and Ogallala Formations and the Meade (?) Group rest unconformably on the older formations in places north of the Arkansas River (pl. 1). The sediments consist chiefly of sand and gravel mixed with silt and clay. The relief of the bedrock surface underlying the deposits varies from place to place, and, accordingly, the thickness of the sediments varies widely. The thickness of the deposits ranges from 0 to 115 feet.

Wells yielding enough water for small irrigation supplies probably can be obtained where these deposits are thickest. The deposits tend to thicken eastward.

PLEISTOCENE(?) SERIES

About two-thirds of the areal extent of the alluvium in the Arkansas River valley of Prowers County consists of terraces; they form a gently southward-sloping upland plain immediately north of the flood plain of the Arkansas. Buried channels, as shown in figure 32, probably northward swinging meanders of the ancestral Arkansas, are concealed under the terrace deposits. The terrace deposits are thin over the scattered bedrock highs that lie beneath them. Locally, the terrace deposits are thin and may lie above the water tably. During wet periods, springs and seeps may issue along the contact between the terrace deposits and the exposed bedrock.

RECENT SERIES

ALLUVIUM

The best aquifer for the supply of stock and irrigation water in Prowers County is the alluvium of the Arkansas River.

Character.—The alluvium in the Arkansas River valley consists of heterogeneous mixtures of sand, gravel, silt, and clay. The materials are generally poorly sorted but may be well sorted locally. sand and gravel deposits are made up principally of rounded to subrounded fragments of igneous and metamorphic rocks derived from the Rocky Mountains. Part of the material was contributed to the valley by the reworking of Pleistocene and Tertiary material of adjacent upland areas. Angular to subangular sedimentary rock fragments make up about 10 percent of the sand and gravel deposits. The angularity suggests that they are derived from the bedrock of the valley floor or the adjacent upland. Clay occurs as thin lenticular or irregular bodies in the sand and gravel beds or mixed with the sand and gravel. A weathered zone consisting of yellowish clay commonly separates the alluvium from the underlying bedrock. weathered zone is overlain in many places by a bed of cemented gravel, which ranges in thickness from several inches to about 5 feet. Loosely consolidated material is interbedded in the cemented zone. Gravel and sand constitute the bulk of the alluvium underlying the flood plain of the Arkansas River. The terrace deposits consist principally of finer materials, except where they are underlain by channel gravel, as shown in plate 4.

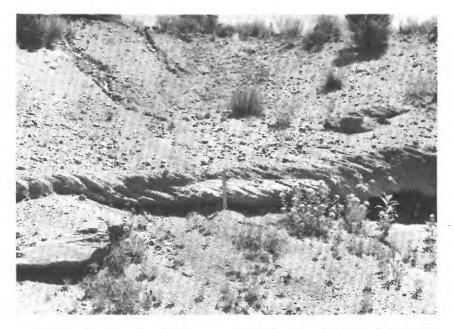


FIGURE 32.—Terrace gravel exposed in a gravel pit northwest of Lamar showing crossbedding in cemented basal section at contact with bedrock.

Distribution and thickness.—The alluvium differs in thickness and lithologic character in the valleys of the Arkansas River and its tributaries. It overlies formations of Cretaceous age in the valley proper and is overlain in part by dune sand of Quaternary age. Alluvium in the valley has two physiographic forms—terrace deposits on the uplands adjacent to the flood plain and alluvial fill in stream valleys. Although several terrace levels were observed at scattered locations north of the valley, no attempt was made to map them separately.

The alluvial fill is bounded on the north by a rather sharp topographic rise from the relatively flat flood plain to the lower terraces or to the bedrock, which is exposed in places along the valley wall. The fill thins to the south, and the exact position of its southern limit is concealed beneath dune sand. This boundary seems to coincide with the northern limits of the dune sand, except in the area east of Granada where the valley fill underlies thick deposits of dune sand.

The thickness of the alluvium on the valley floor ranges from 0 at the edge of the valley to 228 feet in test hole 23–42–8ccc. The location of alluvial-filled channels in the bedrock surface is shown by the contours on plate 6. The thickness of the alluvium in the tributary streams ranges from 0 to approximately 50 feet; the maximum thickness occurs in tributary valleys that receive contributions of sediment from loosely consolidated Tertiary deposits.

Age and correlation.—The alluvium in the valleys of Prowers County is younger than the terrace deposits and the Ogallala Formation. Remnants of several terrace levels were observed by the writers in scattered localities north of the Arkansas River, but their identity has been obscured by slope wash, and they are treated in this report under the general heading of terrace deposits of Quaternary age (pl. 1).

Water supply.—The alluvium constitutes the major aquifer in the area investigated. It is much more productive in the Arkansas Valley than in the tributaries because the materials are thicker, coarser, and better sorted.

The alluvium of the streams tributary to the Arkansas River is capable in some places of providing adequate quantities of water of generally good quality to domestic and stock wells. The quantity of water available depends chiefly upon the thickness and areal distribution of the alluvium. In areas where the alluvium is very thin, small yields may be expected. Where the alluvium is thick and is relatively extensive, moderate yields may be obtained—as in the lower reaches of Clay Creek southeast of Lamar. Systematic test drilling to locate points of maximum saturated thickness should precede well drilling in the alluvium of the tributaries.

The chemical quality of water in alluvium of the shallow tributary streams is influenced by the bedrock beneath and adjacent to the stream. Where the saturated alluvium is associated with bedrock that contains undesirable soluble mineral constituents, the chemical quality of the ground water is impaired. Such bedrock includes shale members of the Graneros, Greenhorn, Carlile, and Niobrara.

DUNE SAND

Dune sand has been deposited in an extensive belt south of the Arkansas River and along Big Sandy Creek and the lower reaches of Two Butte Creek. The dune sand forms a continuous belt along the east bank of Big Sandy Creek, where it covers the old channel. At the confluence of Big Sandy Creek and the Arkansas River, the dune sand blankets the alluvium. South of the Arkansas, the dune sand forms a continuous belt extending from the Bent County line to the Kansas State line. This belt ranges in width from 4 miles in the vicinity of Holly to 1 mile southeast of Carlton. It mantles Cretaceous, Tertiary, and Quaternary deposits along its southern extent.

The sand is composed principally of quartz; however, noticeable amounts of magnetite and pink feldspar were observed in samples from several areas. The fine to medium sand is rounded to subrounded and is well sorted. Locally, where soil zones have been developed, the sand has been loosely consolidated by clay.

The distribution of dune sand, as shown on the geologic map (pl. 1), was taken from detailed soils maps prepared by the U.S. Soil Conservation Service. The dune sand is generally covered with soapweed and sagebrush; however, dunes are active in scattered areas. The topography of the dune sand depends on the stage of evosion and the amount of cover. South of Lamar, part of the dune area has been stabilized by vegetation and forms a hummocky surface, which is almost flat compared to the surfaces of active dunes.

The dune sand ranges in thickness from 0 to approximately 80 feet, as shown on well and test-hole logs. The average thickness of the dune deposits is approximately 35 feet.

The dune sand was probably derived from sand of the Ogallala and Pleistocene Formations of the southern upland and also from the Dakota Sandstone, which shows evidence of much wind abrasion in the southwestern part of the county. The dunes were formed probably during late Pleistocene and Recent time.

Quantities of water sufficient for stock watering have been obtained from wells tapping the dune sand; however, the supply is not dependable and, during drought, wells become dry. The sand dunes act as excellent catchment areas for the precipitation which recharges underlying water-bearing formations.

CONCLUSIONS

In Prowers County, despite fairly large withdrawals of ground water for irrigation and lesser amounts for other uses, the annual withdrawal rate from the aquifers can be substantially increased without significantly depleting the supply.

The four principal water-bearing formations in Prowers County are: The Cheyenne Sandstone Member of the Purgatoire Formation, Dakota Sandstone, the Ogallala Formation, and the alluvium. These formations are capable of yielding large quantities of water to wells in some places; however, in other places, the formations are barely able to supply domestic and stock wells. In some places, the water contains concentrations of chemical constituents undesirable for certain uses.

The Cheyenne Sandstone Member of the Purgatoire Formation is the most extensive but least developed aquifer in the county. The water is suitable for most uses, and potential yields from wells may be greater than those from the Dakota Sandstone.

The next most extensive aquifer in the county is the Dalota Sandstone. In the northern part of the county, where the Ogallala Formation is absent, the Dakota Sandstone is the major source of water even though it may be as much as 850 feet beneath the surface. The overlying formations in this area contain only meager supplies of water of poor quality. Throughout the county, the water from the Dakota Sandstone generally is less mineralized than that from the alluvial deposits and softer than that from all the younger formations. Despite the quality limitations of some of the water, it is used for domestic, stock, and irrigation supplies. In places, wells tapping both the Cheyenne Sandstone Member of the Purgatoire and Dakota Sandstone are capable of supplying water in quantities considered adequate for irrigation. Wells tapping only the Dakota Sandstone commonly yield enough water for small municipal supplies.

The Ogallala Formation yields larger amounts of water to wells than the older formations but is much less extensive, being confined chiefly to the northeast corner and the southeastern part of the county. The largest yields are obtainable from the northeast corner, although the saturated thickness of the deposits generally is greater in the southeastern part; the better yields are due to coarser, more permeable materials. Wells yield as much as 1,500 gpm in the northeast, whereas they generally yield less than 500 gpm in the southeast. This water generally is the least mineralized in the county, although it is harder than the water from the sandstone of the Dakota and Cheyenne.

The quality of the water and the yield of wells in the alluvial deposits varies widely. The largest yields are obtained from wells in the vicinity of Holly, where the alluvial deposits of the Arkansas

Valley are thickest. Saturated sections as thick as 200 feet are common, but from a point a few miles upstream from Holly to the western boundary of the county, saturated sections are more commonly about 50 feet thick. Wells on the north side of the valley generally are more productive than those of the south side. The alluvial deposits of the tributaries generally are much less productive, although those of Clay Creek yield a bountiful supply of water of good quality for the city of Lamar. The quality of water from deposits in this tributary is in marked contrast with that from deposits in Big Sandy Creek, which is too mineralized for most uses. Only thin deposits occupy the valleys of the tributaries; their potential as aquifers is insignificant. Water in the Arkansas Valley does not meet the requirements for good drinking water but is used successfully for irrigation of crops suitable to this area.

Certain changes in lithology were noted during the studies that have a direct influence on the water-bearing properties of aquifers. The diversified character of the Ogallala Formation is one example. Some data suggest that the Cheyenne Sandstone Member is more permeable in a small area south of Holly than it is elsewhere in the county. Further exploration, however, may reveal other areas where it is equally permeable. The alluvium of Clay Creek is more permeable than that of other tributary valleys.

Much evidence indicates that water from, or associated with, consolidated formations younger than the Dakota Sandstone is likely to be much more highly mineralized than water associated with older Cretaceous rocks. An example is the difference in quality between the water in the alluvium along Clay Creek and that in the alluvium along the Big Sandy. Water in the alluvium of Clay Creek has not been in contact with the younger rocks and, except for hardness, generally is of good quality, whereas water in the alluvium of Big Sandy Creek has been in contact with materials derived from the younger rocks, which underlie and are intermixed with the alluvium.

Three major faults and several minor faults affect the occurrence and availability of ground water in the consolidated aquifers. Within a distance of less than a hundred feet, the depth to the top of an aquifer may change as much as 200 feet. Consolidated beds, for example, are displaced near the center of sec. 22, T. 24 S., R. 45 W. Along the fault trace the Dakota Sandstone abuts the Greenhorn Limestone. A well drilled on the north side of the fault would penetrate a part of the Greenhorn Limestone and all of the Graneros Shale before entering the Dakota Sandstone. A well drilled on the south side of the fault would start in the Dakota.

The surface-water resources of the county are closely related to the ground-water resources, especially to those in the unconsolidated aqui-

fers. The alluvium adjacent to the perennial streams is hydraulically connected to the streams in most places. Water withdrawn from the alluvial aquifer, therefore, tends to reduce the flow in the stream. Alluvial and terrace deposits on the streamward side of the irrigation distribution system are, in most places, assured of an abundant supply of recharge water. A major part of the diverted surface water reaches the aquifer by leakage from the distribution system and from the water applied to the land in excess of crop requirements.

Withdrawal of ground water in the area being replenished by surface water has not caused any noticeable depletion of the ground-water reservoir. Withdrawal probably could be increased substantially without depleting the ground-water reservoir significantly.

Radiochemical analyses made of samples of water from five wells apping the Cheyenne Member and Dakota Sandstone show that the radium content of water from these aquifers is substantially higher than that of water from the Arkansas River at Lamar. The radium content of the water from the municipal wells at Wiley is at least twice the maximum permissible concentration for drinking water recommended by the Advisory Committee on Revision of 1946 Drinking Water Standards (U.S. Public Health Service, 1961, p. 944). Further study should be made of the nature and extent of the above-normal concentrations of radium in the water of the Dakota and Cheyenne Sandstone Member of the Purgatoire.

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